ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF ARCHITECHTURE AND CIVIL ENGINEERING

LEVEL OF SERVICE ANALYSIS FOR TWO- LANE, TWO-WAY FEDERAL HIGHWAY OF ETHIOPIA

CASE STUDY: CHANCHO-SULULTA, SEBETA-TULUBULO AND ADDIS ABABA-SENDAFA ROAD SEGMENT

BY

CHIROTAW YIRGA

ADVISOR: DR. MELAKU SISAY

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDENTS IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCEINCE IN CIVIL ENGINEERING

(ROAD AND TRANSPORT ENGINEERING)

SEPTEMBER 2017

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DECLARATION

I, certify that the research work titled "**LEVEL OF SERVICE ANALYSIS FOR TWO-LANE, TWO-WAY FEDERAL HIGHWAY OF ETHIOPIA, CASE STUDY: CHANCHO-SULULTA, SEBETA-TULUBULO AND ADDIS ABABA-SENDAFA ROAD SEGMENT"** is my work. The work has been presented elsewhere for assessment where material has been used from other source it has been properly acknowledged/referred.

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LIST OF ABREVATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway Transport Organization
ADT	Average Daily Traffic
ERA	Ethiopian Road Authority
ATS	Average Travel Speed
ATSd	Average Traffic Speed In Directional
BFFS	Base Free- Flow Speed
DHV	Design Hourly Volume
FFS	Free Flow Speed
HCM	Highway Capacity Manual
HCS	Highway Capacity Software
HSM	Highway Safety Manual
LOS	Level Of Service
NCHRP	National Cooperative Highway Research Program
PFFS	Percent Free-Flow -Speed
PHF	Peak Hour Factor
PTD	Percent Time-Spent-Delay
PTSF	Percent Time-Spent-Following
TRB	Transport Research Board of America
TWOPASS	Two way passing lane software
UNECA	United Nation Economic Commission for Africa

ABSTRACT

This research has focused on the level of service analysis of selected two-lane, two-way Roads Segment based on prevailing field condition. The study has predicted the performance of those selected two-way two-lane roads how they perform in the future five years for projected traffic starting from 2017 to 2022 based on exhibited traffic growth trend. The analysis of Level of service for current and future five years has been performed using HCS, 2010 software. The data required as an input in HCS 2010 software were collected from field, from ERA traffic count record. The results of HCS 2010 software analysis has shown that those roads segments are operating currently at undesirable levels of service between C and E. The future five years analysis has shown that LOS fall to the undesirable level between C and E.

The computed 85th percentile operating speed adopted as speed limit to compute BFFS. BFFS has been performed by adding 10 mil/h in to 85th percentile operating speed. By using BFFS that obtained from 85th percentile operating speed and by changing lane width from 3.5m to 3.66m and shoulder width from 1.5m to 3m, LOS simulation has been performed. The result obtained from this simulation shows that LOS for Addis Ababa-Sendafa, Sendafa-Addis Ababa, and Sebeta-Tulubulo roads segment has been improved and fallen in to B. However, by using BFFS value only that obtained from 85th percentile operating speed and by changing lane width from 3.5m to 3.66m and shoulder width from 1.5m to 3m, LOS for Sululta-Chancho, Chancho-Sululta, and Tulubulo-Sebeta still has been fallen in undesired level as LOS governed by both ATS and PTSF values. To improve the LOS of those roads segment, the study has assigned passing lane and simulated in to HCS 2010. LOS has been fallen in to B category by using 0.8mil for Chancho-Sululta, 0.9mil for Sululta – Chancho and 1.1 mil for Tulubulo-Sebeta roads segment. Even though the riding quality of those two-lane, two-way roads segments are in good condition, LOS decline from time to time and travel time highly affected due to increasing the volume of traffic and proportion of truck. Therefore, this study recommend that appropriate geometric parameters design such as increasing lane and shoulder width and provision of passing lane is required to improve LOS to desired level.

Key Word: Level of Service, Average travel speed, Percent time spent following and two-lane, two-way road;

CHAPTER ONE

INTRODUCTION

The Government of Ethiopia is recognizing the importance of road transport in supporting social and economic growth of the country and its role as a catalyst to meet poverty reduction. To meet the targets, government of Ethiopia has given high attention on improvement of the quality and size of road network by investing significant amount of resource. In this regard, Ethiopia Road Authority has made great effort in expanding and improving the road network as part of development of the infrastructure, thus enabling sustainable economic and social development of the country. Ethiopian Roads Authority has a vision to satisfy the road user by increasing the road networks and plays it role for the development of the country towards to become middle-income countries in 2025.

Ethiopian Roads Authority has constructed two-lane, two-way highways in different geographical parts of the country whereby they provide variety of transportation services. Although the riding quality of the two-lane, two-way road network is one of the criteria to satisfy the demand of road user, it is also needs to put emphasize on performance of the service provided for the current and future use. Mostly, the quality of service in transport has a linkage to the satisfaction of the users and the benefits they should get in using a given road. It has a direct adverse effect on economy growth in considering the losses for any travel time or, the improvement of the service, which should transform these losses into benefits.

In two-lane, two-way roads lane changing and maneuvering are restricted. Due to this reason, passing and maneuvering are performed using the opposing lane of travel when sufficient sight distance is available and the opposing lane becomes free. Hence, normal traffic stream in one direction of two-lane, two-way roads influence the flow in other direction (HCM, 2000).

The most constructed Federal roads in Ethiopia are two-lane, two-way where they provide a variety of transportation function. The main objective of the provision of these two-lanes, two-way roads are for an efficient mobility of people and goods from one place to other place. To maintain this objective, the flow of traffic shall be uninterrupted due to different reason.

However, in Federal roads of Ethiopia traffic congestion has been observed due to presence of high proportion of heavy vehicles. Heavy vehicles travel in slower speed due to their performance and the smaller vehicles travel with undesirable speed behind the heavy vehicles due to presence of high proportion of heavy vehicles and due to increasing volume in the opposite direction. In this case, the efficient mobility of people and goods significantly affected. To maintain the appropriate traffic flow of these two-lane two-way roads, HCM has recommend implementing the operational performance analysis based on prevailing condition and taking the appropriate mitigation measure to improve the observed LOS for better future use.

Fig 1: Maneuvering using opposite lane observed in Addis Ababa- Sendafa Road

Fig 2: Platoon observed in Addis Ababa-Sendafa road

To know the quality of traffic flow, the operational performance analysis based on prevailing field condition and design applications for two-lane, two-way roads have significant importance. Different literature showed the operational performance is computed using procedural manual, which published as highway capacity and performance manuals. The basis for the development of this procedural manuals are the facts that obtained from the outcome of customer satisfaction survey and those procedural manual adopted by many countries (HCM, 2000). However, based on researcher review, Ethiopian Road Agencies have not yet published procedural manuals based on the outcomes of customer satisfaction survey for the level of service analysis of two-lane, two-way roads. Instead, the researcher has used Highway Capacity Manual of HCM 2010 for this study, which recently published in the United States of America by the Transportation Research Board in 2010 to outlines the capacity and Level of Service (LOS) analysis procedures.

Using the procedures that outlined in HCM 2010, the performance of the roads typically has been described using LOS as a letter scheme from A to F and which intended to describe traffic conditions for an existing or proposed facility operating under current or projected traffic demand. As indicated in HCM 2010, there are two performance measures on two-lane, two-way highways. These are Percent Time-Spent-Following (PTSF) and Average Travel Speed (ATS). Percent Time Spent Following (PTSF) refers to the percentage of travel time in which a vehicle trapped in a platoon on a two-lane highway being unable to pass slower vehicles. Average travel speed (ATS) is the length of highway divided by the average travel time of vehicles on the segment and is considered to be a reflection of the mobility on a two-lane highway (TRB, 2000).

One of the foundations of the HCM is the concept of LOS. Current practice designates six levels of service ranging from A to F, with level of service “A” representing the best operating conditions and level of service F the worst operating condition (HCM, 2000).

The LOS is an important indicator used to evaluate the performance of a highway facility and defined as qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers. The facility performance prediction and knowledge is a fundamental in design, planning, operation, and layout of road network sections (HCM, 2000).

The operational performance and capacity of highway are influenced by several factors such as road conditions (pavement), gradient, lane and shoulder width, lateral clearance, slow moving vehicles like heavy vehicles, driver population that shall be taken into accounts in the analysis. The directional split, presence of slow moving vehicles in the traffic stream, environmental condition such as wet pavement, rain, darkness, fog, parking regulation affect the driver performance and capacity (HCM, 2000).

On the other hand, the LOS is an important indicator of two-lane, two-way roads safety. Different highway safety related manual is established to identify factors contributing to crashes, associated potential countermeasures to address these issues and estimate potential crash frequency and severity on highway networks. The factor contributing for crash in two-lane, two-way may also contribute for the reduction of LOS. Thus, the analysis of LOS and safety performance of the road concurrently is important.

Therefore, the roadway performance analysis is very important to make a close follow up of quality of service and to predict the need of traffic management and improvement in future on road network in urban and rural areas based on LOS analysis result.

In this regard, this research has a contribution to know the level of the service of the selected road for this study and suggest how to improve the performance.

1.1. Statement of the Problem

Providing mobility for people and goods is most essential function of transportation in Ethiopia. The Government of Ethiopia has launched Road Sector Development Program Phase I to Phase IV for rehabilitation and upgrading of existing roads and expansion of the road network. The Government of Ethiopia has also paid high attention and investing significant amount of resource to improve the road network in the country thereby to meet the Growth and Transformation Plan by delegating the Ethiopian Roads Authority to facilitate the planned development and transformation. Starting from its establishment, the Ethiopian Roads Authority has constructed more than 134,000 km Roads in different parts of the country by investing enormous amount of money for design and construction. Among these constructed roads in different part of Ethiopia, two-lane, tow-way roads are essential element of transportation for the mobility of people and goods.

The most constructed roads in Ethiopia are two-lane, two-way roads. The main objective of provision of two-lane, two-way roads in Ethiopia is to enhance the efficiency of mobility of people and goods via facilitating growth of the country. Most of the times, the traffic congestion is observed in two-lane, two-way roads in Ethiopia. This shows the quality of roads in terms of traffic flow is not in a good condition and the intended purpose of the road is adversely affected.

Moreover, in two-lane, two-way road passing demand increases rapidly as volume and proportion of heavy vehicles increases. Passing capability in the opposing lane also is declined as volume increase (HCM, 2000). Consequently, the travel takes longer time and intended purpose of the roads of those two-lanes, two-way is not being achieved. When network approaches capacity limits, congestion and queues start to be developed. As traffic slows down, the time and cost increase and the quality of service decrease. Furthermore, it is observed that head on crashes on two-lane, two-way road in Ethiopia during maneuvering which cause for the loss of life and property.

ERA traffic count from 2002 to 2016 shows the traffic volume increase from time to time in the constructed two-lane, two-lane roads that selected for this study. To illustrate this, Addis Ababa- Sendafa road segment Average Daily Traffic(ADT) was 1355 in 2002 and growth to 2394 in 2016; in Addis Ababa-Chancho road segment ADT was 687 in 2002 and growth to 4344 in 2016;in Sebeta-Tulubulo road segment ADT was 580 and growth to 1857 in 2016. ERA traffic count also shows both Average Annual Daily Traffic (AADT) and ADT in all the road segments increase from 2002 to 2016. It implies, even though the riding quality of two-lane, two-way roads is in good condition, the performance is declined due to fast growth of the traffic volume, heavy vehicle percentage and travel time affected. In addition to this, congestion is observed in different two-lane two-two way roads, which shows the performances of those roads, are not in the good condition. As a result, the road user satisfaction will be decreased related with the increase of traffic volume. In connection to this, it had better to carry out LOS analysis to know the actual/operational performance and seek the improvement of performance mechanism by incorporating the result obtained from LOS analysis in to planning, design, construction, and operation phase.

Fig 3: Traffic Congestion were observed within 10 minute in Sululta-Chancho Road Segment

From the above figure, it can be noted that the LOS of the road or operational performance of the road is not in good condition. LOS is the best-known measure for qualitatively assessing the quality of a roadway (Ensley, 2012). LOS is also an important indicator to know the quality of the road service provided and to plan for the future improvement by identifying the factor that influences performance of service.

However, as per the researcher review, there is no experience related to performance analysis or level of service analysis of road in Ethiopia based on prevailing condition of the road to know whether the road functioned based on the intended purpose in terms of quality of traffic flow.

In this regard, this study will play its own role to know current LOS condition and predict the future LOS of the two-lane, two-way road selected for this study and to suggest for future improvement in terms of quality of traffic flow for the transportation of road.

1.2. Scope of the Research

The study is limited to LOS analysis for the two-lane, two-way roads selected from Federal network of Ethiopia particularly for 5km roads segment of Sebeta- Tulubulo, Sululta-Chancho and Addis Ababa-Sendafa. The study focus on the analysis of LOS of these roads segment for prevailing condition and to predict LOS for the future-five years starting from 2018 until 2022.

1.3. Research Questions

The study will address the following research questions:

- What is the importance of LOS analysis of the road based on prevailing operational condition?
- How can LOS analysis of the road perform based on prevailing operational condition?
- What is LOS of road look like in Ethiopia for two-lane, two-way Federal roads

1.4. Objective

1.3.1. General Objective

The general objective of this study is to evaluate the LOS of two-lane, tow-way Federal highway of Ethiopia, particularly for 5km segment of Sebeta- Tulubulo, Sululta-Chancho and Addis Ababa-Sendafa roads based on prevailing field condition and forecasting condition.

1.3.2. Specific Objectives

The specific objectives of this study includes-

- To determine LOS or operational performance of two-lane, two-way roads based on prevailing field condition.
- To predict and evaluate the LOS over a period of 5 years.
- To examine the effect of lane and Shoulder width and other road's parameter on LOS improvement.

CHAPTER TWO

LITERATURE REVIEW

In this section of the research thoroughly reviews the previous appropriate research that conducted in the related field of study of performance as well as level of service analysis of two-lane, two-way roads has been carried out . Moreover, the researcher thoroughly reviewed the related research to formulate ideas that have important perspective for this study. This chapter provides an idea of the issues that desires to address and described as below.

2.1. Definition of Two-Lane, Two-Way Highway

Most of the time, the decision to provide a two-lane highway is not justified on demand and capacity requirements alone, but a minimum level of service requirements which justify at least one travel lane in each direction for safety, convenience, and tolerable operating conditions (TRB, 1965). This brief description shows the implementation of LOS for two-lane, two-way highways are very important parameter for assessing the performance of two-lane, two-way highways. A good performance measure describes the observations of the traffic facilities users and is useful for traffic Engineers to analyze the facilities (Luttinen, 2000).

Two-lane highway may include longer sections of two-lane highway with homogenous cross sections and relatively constant demand volumes and vehicle mixes over the length of segment. Two-way segment may be located in level or rolling terrain. Two -lane highway in mountainous terrain or with grades of 3 percent or more for length of 1.0 km or more can not be analyzed as two-lane segments. Instead, they are analyzed as specific upgrades or downgrades. Performance measure for the two-way segment methodology apply to both direction of travel combined (HCM, 2000).

Fig 4: Two-lane, two-way road (Sebeta-Tulubulo)

Two-lane, two-way highways define in the HCM as undivided roadway with two lanes, one lane utilize by traffic in each direction and classify as either:

Class-I – These are two-lane, two-way highways where a motorists expect to travel at relatively higher speed. These two-lane, two-way highways include major intercity routes, primary arterials connecting major traffic generators, daily commuter routes, or primary links in state or national highway networks generally. Class-I facilities most often serve long distance trips or provide connecting links between facilities that serve long distance trips.

Class-II – These are two-lane, two-way highways where the motorists do not expect to travel at higher speed. This includes two-lane, two-way highways that function as access routes to Class -I facilities, serve as scenic or recreational routes that are not primary arterials, or pass through rugged terrain. Class-II facilities most often serve relatively short trips, the beginning, and ending portions of longer trips, or trips for which sightseeing plays a significant role.

Class-III – These are two-lane, two-way high where the motorists do not expect frequent passing opportunities, or to travel at higher speeds. Scenic routes, recreational routes, or routes that pass through moderately developed areas (small towns) are typically an example of Class -III. These routes generally have lower posted speed limits, and in these situations, motorists usually do not mind following other vehicles or traveling at slower speeds, as long as they are able to travel at a speed close to the posted speed limit.

The two-lane, two-way highways can also classify based on motorist expectation rather than highway functionality (Durbin, 2006). For example, if motorists feel that high speeds are not feasible on the corridor, a highway connecting two major cities that passes over a rugged mountain pass can be classify as Class-II rather than Class-I. Furthermore, two-lane, two-way highway classify as highway facilities that function under uninterrupted-flow, where operations largely based on an interactions between vehicles moving in the same direction as well as in opposing directions. Pure uninterrupted flow exists primarily on freeways, where traffic is free to travel without hindrance from external interruptions, such as: intersections at grade, driveways other forms of direct access to adjoining lands traffic signals and “STOP or YIELD” signs and other interruptions external to the traffic stream. Furthermore, traffic operations on two-lane, two-way highways differentiate from the other uninterrupted-flow facilities by the following condition (HCM, 2000):

- lane changing and passing are possible using only the opposing lane of travel,
- passing demand increases rapidly as traffic volumes increase, and
- Passing capacity in the opposing lane declines as volumes increase

From the above characteristics, unlike other uninterrupted-flow facilities, normal traffic flow in one direction influences flow in the other direction on two-lane, two-way highways. As many two-lane, two-way highways connect major traffic generators (i.e. universities, stadiums, malls, etc.) they need to provide safe and timely travel. Passing ability of faster moving vehicles, particularly on two-lane, two-way highways affect the capacity, safety, and LOS (Polus et. al., 2000). The following variety factors also influence the Passing ability on two-lane, two-way highways.

- Traffic volumes of through and opposing traffic
- The Speed difference between the passing and passed vehicles
- Highway geometry
- Available sight distance
- Driver-reaction time and gap acceptance (human factors)

As the functionality characteristics of these facility decreases, passing opportunities become fewer, thus increasing the difficulty of vehicles to pass. This difficulty to pass on two-lane, two-way highways can create vehicular travel delay. If vehicles cannot pass slower moving vehicles immediately, platoons will begin to form. Vehicle platoons increases the proportion of short headways and decreases mean travel speed on the highway. This reduces the capacity of two-lane, two-way highways consequently decreasing safety and level of service on the roadway. Therefore, delay indicated by the formation of vehicle platoons, is severely reduced traffic operational performance of two-lane highway.

2.2. History of Performance Analysis of Two-Lane Highway

Clear understanding of how much a given traffic facility can accommodate and under what operating conditions is one of the most critical needs in traffic engineering. These important issues address in different highway capacity and level of service analysis manual under different operation condition. The basis for all capacity and LOS analysis is a set of analytic procedures that measure the resulting quality of operations and relate the demand or existing flow levels to the geometric characteristics and controls of the road. There are many developed models, which used to perform capacity and LOS of the road based on regression analysis of significant data, theoretical algorithms, and/or laws of physics and on the results of simulation. The main analysis procedures for two-lane highways used in the United States as wells as in many other countries are those outlined in the HCM 2010, the National reference for capacity analysis procedures on highways and other transportation facilities.

The HCM is the principal publication of the TRB of the National Academies of Science and Engineering. It has become the single most important technical document used throughout the United States of America and other nations as a guideline to the analysis the highway capacity and LOS (R.P.Roess and E.S.Prassas, 2004).

Bureau of Public Roads and the Highway Research Board's Committee of United States, published the first HCM in 1950. The 1950'S HCM provided a standard method for highway capacity analysis. This manual used to analyze functionality of two-lane, two-way highways, with the performance measure for practical capacity being the operating speed (Luttinen, 2001). The Manual contained three basic types of capacity:

- Ideal capacity, capacity under ideal conditions,
- Possible capacity, capacity under prevailing conditions, and
- Practical capacity, maximum traffic volume under prevailing conditions
  Without traffic conditions becoming "unreasonable

Highway Research Board Committee also developed a new HCM in 1965, which include a new concept of LOS. The second edition of the HCM extended the idea of practical capacity from the first HCM to the well-known six levels of service (LOS) scheme. In this edition of HCM, LOS expressed in terms of operating speed as the governing service measure and the traffic volume limitation as a supplementary service measure (Luttinen, 2001). The 1965 HCM outlined a five-step process for calculating LOS on two-lane, two-way highways. This procedure involved calculating a base volume and then dividing the given demand volume by the base volume to obtain a volume to capacity ratio (v/c).

After twenty years: in 1985, TRB published a third modified HCM 1985. The development of this third edition of the HCM, considered the average speed as an adequate measure of the balance between passing demand and passing supply. The HCM 1985 procedures utilized an assumption that cars were traveling in platoons when they were traveling less than their desired speeds at headways less than five seconds. The percentage of vehicles that they travel less than their desired speeds at headways less than five seconds were used as a surrogate measure (Luttinen, 2001) which termed as percent time delay(PTD).

A few years ago, the fourth edition of the manual, HCM 2000 was established. This manual renamed the percent time delay (PTD) to percent time-spent-following (PTSF). This was done because the expression was based on time spent traveling in platoons, rather than delay, which was causing confusion with the users of the HCM. Further, it was determined that the five-second time headway parameter in 1987's HCM was too high and users of the manual suggested that a lower value would provide results that are more accurate. By changing the definition for when a vehicle is being delayed from headway of 5 seconds, as given by the Manual, to headway of 3.5 to 4.0 seconds, more useful level-of-service categories result (Guell, 1988).

From this evolution, the current performance measure for two-lane, two-way highways, PTSF, was developed and introduced to the engineering community. In particular, the section covers the procedure for using PTSF in estimating performance on two-lane, two-way highways. Highway Capacity Manual: Capacity and LOS Concepts LOS used to evaluate the performance of two-lane, two-way highways as early as the 1960's (Durbin, 2006).

All the edition of HCM in common developed LOS, which has six groups, designated by the letters A-F. Each HCM since 1965 has outlined a procedure for determination of level of service provided by any two-lane highway section with uninterrupted flow. This method for analyzing the performance of two-lane, two-way highways has evolved greatly in the past 40 years, which has led to LOS concept as outlined as follow (TRB, 2000).

- **Level A:** describes the highest quality of traffic services in a facility, when motorists are able to travel at their desired speeds. Generally, this highest quality would result in average vehicle speeds of 90 km/h (55 mi/h) or more. Moreover, drivers do not delay more than 35 percent of their travel time by slow moving vehicles.

- **Level B:** marks the beginning of stable flow, where speeds of 80 km/h (50 mi/h) are achievable. The demand for passing to maintain desired speeds becomes significant, with drivers delays up to 50 percent of the time.
- **Level C:** still experiences stable flow, where the attainable average speed slows to nearly 70 km/h (44 mi/h). Traffic is susceptible to congestion, with delay reaching 65 percent of the travel time.
- **Level D:** experiences unstable flow and represents the highest maintainable traffic volume without a high probability of breakdown in traffic flow. Travel speeds are nearly of 60 km/h (37 mi/h), with no motorists experiencing delay for more than 80-85 percent of their travel time.
- **Level E:** represents capacity flow where speeds slow to nearly 40 km/h (25 mi/h). Passing is virtually impossible at LOS E, with platoon becoming intense.
- **Level F:** represents congested flow with relatively unpredictable characteristics and traffic demands that exceed capacity. In this, once the facility achieved level F, the LOS analysis is not performed.

The two performance measures that used to determine the LOS for two-lane, two-way highways, are PTSF and ATS. Both PTSF and ATS apply as performance measures for Class I highways, while only PTSF apply for Class II highways. It is important to note that the ATS was selected to be used in coordination with PTSF for Class I highways because it make LOS sensitive to design speed and enables the use of the same criteria for both general and specific terrain segments (Luttinen, 2001). According to the above description of PTSF, it is only concerned with the time when vehicles involuntarily travel in platoons and are unable to obtain their desired speeds due to the inability to pass slower-moving vehicles.

According to the HCM 2000, it is often difficult to measure PTSF in the field. A surrogate field measure would be the percentage of vehicles driving at slower than desired speeds being unable to pass slower moving vehicles. Therefore, the HCM suggests using the percentage of vehicles traveling with headways of less than three seconds as a surrogate measure (TRB 2000). Besides the surrogate measure described above, the HCM 2000 also outlines a formal Procedure for determining PTSF. As described in the HCM 2000, percent time-spent following can be determined for either two-way segments or directional segments. Two-way segments may include longer sections of two-lane highway with homogeneous cross sections, relatively constant demand volumes, and wide vehicle mixes over the length of the segment. Performance measures for two-way segments apply to both directions of travel combined. Conversely, directional segments carry one direction of travel on a two-lane highway with homogeneous cross sections and relatively constant demand volume and vehicle mix. Directional analysis is most applicable for steep grades and for segments containing passing lanes.

From evolution of HCM, the researcher understood that capacity and performance analysis based on prevailing condition is a big concern in United States of America (USA). In the development of HCM, It is also observed that a gradual improvement of the performance of the road is required by modifying the analysis tools/ manuals via incorporating a feedback from different stakeholders in the respective field.

2.3. Level of Service Analysis Practice

Many developed countries such as Germany, Great Britain, Denmark, Spain, Canada, Australia and others follow different level of service analysis guideline (Luttinen, 2001). For example, Germany guidelines use average travel speed of passenger cars as level-of-service measure. The following table 1 shows LOS for different value of average travel speed of passenger car in Germany guideline.

Table 1: Limiting values for LOS on Germany two-lane highway (Luttinen, 2001)

LOS	**ATS of passenger car (km/h)**
A	80
B	70
C	60
D	50
E	50
F	40

Great Britain, in the capacity analysis heavy vehicles were estimated as 1.5 passenger car equivalents. The measurements did not cover congested conditions, but the capacity of a two-lane highway has taken as 1,100 veh/h per standard lane at standard vehicle composition (15 percent heavy vehicles), regardless of road layout or directional split. The British studies have established design standards based on ‘practical capacity’ of 1950 HCM (Bureau of Public Roads, 1950). The selection of appropriate cross section is based on average annual daily traffic (AADT) flows for the 15th year after opening and on recommended design flows for different road types. The design volume (AADT) for a normal 7.3 m two-lane highway is up to 13,000 vehicles, while wide 10 m highways are suggested for volumes of 10,000 to 18,000 vehicles. Design flows are expressed in vehicles, not equivalent passenger car units. (O Flaherty, 1997)

In Denmark, Levels of service are expressed in terms of volume-to-capacity ratios (v/c) and average travel speeds, without any classification, such as A–F used in the HCM. The Danish method does not have any adjustment for terrain type. The effect of vertical highway geometry is included only in the adjustment factor for heavy vehicles (fHV). There is also an additional adjustment factor for slow vehicles, such as tractors or harvesters (Luttinen, 2001).

The Australian capacity manual follows very closely the 1985 HCM (TRB, 1985). The manual, however, uses both percent time delayed and average speed as service measures. The average speed criterion in table 2 below has been defined for highways with a design speed equal to or greater than 100 km/h (Austroads, 1988).

Table 2: LOS criteria for average speed (km/h) in the Australian Capacity manual (Austroads, 1988)

LOS	**terrain**		
	Level	**Rolling**	**Maintain**
A	>93	>91	>90
B	>88	>86	>86
C	>83	>82	>78
D	>80	>78	>72
E	>72	>64	>56
F	>72	>64	>56

However, many Researchers believe that the HCM is a principal guide in transportation decision-making, planning, and design (Kittelsonet et al, 2001). Washburn and McLeod studied the planning methods of HCM 2000 in order to create a with planning-analysis capabilities for two-lane and multilane highways (Ensley, 2012). The capacity estimates should be considered as crude estimates, and more emphasis should be given to level-of-service analyses.

2.3.1. Scientific Studies carried out related to LOS

After HCM 2000 procedure was introduced, researchers in United States and in many other countries carried out studies to assess the new procedures of evaluating traffic performances on two-lane roads.

In order to define LOS on Finnish two-lane roads, Luttinen in 2000a used data obtained from 20 automatic traffic recorders in the summers of 1997 and 1998 for 15-minute time intervals. In this study, Effect of heavy vehicles was eliminated by using refined passenger car flow rates. Both linear and concave speed-flow models were estimated. It was observed that speed reduction due to increasing flow rate was smaller on Finnish highways in comparison to the HCM 2000 estimate. A linear relationship was also established between directional capacity and opposing flow rate. The effect of the flow rate was found out more than the effect of opposing flow on ATS. The study suggested that directional distribution should be considered for determining ATS (Luttinen, 2000a).

In another study, Luttinen in 2000b gave an overview on traffic flow on two-lane highways in Finland. It was found out that when numbers of heavy vehicles increased the demand of passing and platooning increased in the same direction of flow of heavy vehicles. Due to the no use of free space in opposing lane by major flow, it was found that density was not an effective measure for two-way flow on the two-lane roads. The two-lane highways analysis was founded that upon directional analysis and conformed to HCM 2000. Effect of directional distribution was found out in random traffic for two-way PTSF. A speed-flow curve was obtained with a steeper slope in case of high free flow speed by studying standard deviation of ATS. It was found out that when flow rate of heavy vehicles increased then the marginal impact of heavy vehicles decreased. In a separate study, Luttinen in 2000(c) analyzed PTSF as a performance measure of two-lane roads by collecting data from two-lane highway in Finland. Using this data, which was based on traffic volumes in the observed and opposing directions, a model was developed to determine PTSF. It was found that HCM 2000 overestimates PTSF for Finnish two-lane roads and calibration needs to be carried out for local condition. Additionally, PTSF measured from the directional analysis was found to be higher than those measured from the two-way analysis (Luttinen, 2000b).

Dixon and other in 2002, tried to validate the HCM 2000 procedure by using data collected at five locations along United State-12 in the state of Idaho, Untied State of America. They used the term percent following for the HCM 2000 defined surrogate field measure of percentage of vehicles with headways less than three seconds TWOPAS simulation model was utilized in order to have additional insight. Inconsistencies were noticed between directional and two-way analysis procedure of PTSF estimate. Two-way analysis was found to be superior in terms of accuracy, though both of the procedures along with TWOPAS estimates produced PTSF estimates, which were substantially higher than the percent following estimate observed from field data (Dixon et al, 2002).

Van As and Van Niekerk in 2004 examined various performance measures as a part of developing new methodology and simulation model for two-lane roads in South Africa. The developed model utilized queuing theory to simulate the change in queue or platoon length over the length of a road. Among different performance measures, follower density (number of followers per km per lane) showed maximum potential as it incorporates three different performance measures into one, namely, percentage followers, traffic flow and travel speed. Thus, this measure of effectiveness can provide better idea about the situations when capacity upgrading is warranted (Van as and Van Neikerk, 2004).

Romana and Perez in 2006, used threshold speed value to measure LOS in Spain for two-lane roads which was defined as the minimum speed accepted by road user while traveling on a uniform road section under heavy flows and platooning traffic. For the study Measure of effectiveness as defined in HCM 2000 were used. It was found that PTSF is required to be calculated only when ATS is greater than some threshold value, otherwise platooning would be behind speed in importance in the view of drivers. The results carried out from the study were found out to be very close to driver perception (Romana and Perez, 2006).

Durbin in 2006 carried out a study to find out PTSF by using two new methodologies, namely, weighted average approach and probabilistic approach as it was considered that the methods used in HCM 2000 were not appropriate to find out the performance on two-lane roads. The weighted-average approach was intended to estimate PTSF by classifying the vehicles as per their performances and assessing their effect on the traffic stream. The probabilistic method was used to estimate PTSF by finding out the probability of vehicles traveling unwillingly within a platoon at a speed lower than their desired travel speed. For testing these two approaches, data were collected from the three different sites in Montana, United States America. The study found that when the number of vehicles inside a platoon increased, the mean travel speed of the platoon reduced. Vehicle travel speeds and time headway were observed to have a direct relationship among them. Travel speed went up when the time headway increased up to 6 seconds, beyond which the relationship flattens, as there was not so much increase in speed with the increment of headway values. Weighted-average approach performed the best when vehicles were classified by their performance. Comparison with the HCM 2000 method revealed that both the methods could provide lower values of PTSF, thus these two methods displayed the potential of eliminating the overestimation observed with the HCM 2000 procedures. The probabilistic approach was found to be superior as it constantly showed better performance in comparison to the weighted average method. PTSF value estimated from the probabilistic approach was observed to be very sensitive to traffic volume, its temporal variations, heavy vehicles percentage, and the effect of passing lanes (Durbin, 2006).

Brilon and Weiser in 2006 analyzed traffic performance on two-lane roads in Germany. They used density (the traffic volume divided by average travel speed of passenger cars) as a measuring of effectiveness for defining the LOS for two-lane roads. In Germany, PTSF had never been considered as a significant measuring of effectiveness as it lacks the ability to directly convey the degree of efficiency of traffic operations on two-lane roads. A simulation model was calibrated to produce speed-flow diagram for all the types of two-lane rural roads. A density of 40 km/h was found to be the typical critical threshold beyond which traffic breakdown occurred. This service measure of density has been incorporated in German Highway Capacity Manual also was used by researchers at Montana State University as various performance measures (Al-Kaisy and Karjala, 2008). To investigate performance on two-lane roads which were average travel speed, average travel speed of passenger cars, average travel speed as a percent of free-flow speed, average travel speed of passenger cars as a percent of free-flow speed of passenger cars, percent followers, and follower density.

Using graphical screening, correlation, and regression analysis methods, a number of relationships were established between performance indicators and major platooning variables. It was found out that follower density has highest correlation with platooning variables. It considered traffic level and can be estimated easily in field in comparison to PTSF. This study found follower density to be a potential service measure on two-lane roads followed by percent followers.

Polus and Cohen developed theoretical and empirical relationships in 2009, for measuring the quality of flow and for a new LOS measure on two-lane highways. For a purpose of five different parameters pertinent to estimation of the flow characteristics on these highways were considered, namely, flow, traffic intensity (ratio between the average time spent in the first position when waiting for an appropriate gap and average inter-arrival times at the back of the queue), average platoon length, PTSF and freedom of flow. PTSF was measured directly by estimating number of headways inside and outside the platoon. PTSF turned out to be an appropriate measure to estimate LOS and evaluate delay costs because it can assist in the calculation of the time lost in platoons, which again can be translated to monetary values (Polus and Cohen, 2009).

Pursuant to HCM 2010, base free flow speed is determined by adding 10mil/h to the speed limit. A posted speed limit, as a matter of practicability, it is the highest speed that might be used by drivers. Instead, it usually approximates the 85^{th} percentile speed value determined by observing a sizable sample of vehicles. Such a value is within the 15-km/h speed range used by most drivers (AASHTO, 1900). 85^{th} percentile speed is the speed below which 85 percent of motorists travel and frequently used to set speed limits (Fitzpatrick et al, 2003). The 85^{th} percentile speed is the speed at or below which 85 percent of the free-flowing vehicles travel. Traffic engineers have assumed that this high percentage of drivers will select a safe speed based on the conditions at the site. The 85^{th} percentile speed has traditionally been considered in an engineering study to establish a speed limit. In most cases, the difference between the 85^{th} percentile speed and the average speed provides a good approximation of the speed sample's standard deviation (TRB, 1998). The effect of speed limit on the standard deviation of speeds increased as the geometric standard of highways improved. Speed limits 80 km/h and 100 km/h decreased mean speed, 85 % speed, and standard deviation of speeds, and decreased passing demand (Luttinen, 2001).

Many researchers have suggested that the speed limit of the road shall be 85^{th} percentile of operating speed. From the plot of roadway variable and 85^{th} percentile, the following factors are affecting 85^{th} percentile or posted speed limit (Fitzpatrick et al, 2003).

- The functional classes and roadway design class have direct relationship with 85^{th} operating speed. Functional classification of the road also related to design standard, which set different values for geometric elements of roads. The geometric elements of the road also directly or indirectly affect operating speed,
- Access point density is the number of access points (driveways and intersections) per mile. Access point density also has a strong relationship with 85^{th} percentile speed with higher speeds being associated with lower access densities.
- Lower speeds occur as the level of pedestrian activity increases or affect 85^{th} percentile speed.
- The absence of either centerline markings or edge line markings is associated with lower 85^{th} speeds.
- As the distances between features that have influence on a driver’s speed, such as a signal or sharp horizontal curve, increase, speeds increase.
- Speeds on roadways with shoulders that had widths equal to or greater than 6 ft. had speeds above 50 mph.
- There is no evidence that the presence of curb and gutter results in lower speeds for a facility.
- Fewer lower speeds are associated with larger total pavement width
- Turnouts

Speeds on roadways with shoulders that had widths equal to or greater than 6 ft had speeds above 50 mph. Speeds on roadways with shoulders between 0 and 4 ft also had speeds up to 50 mph with most being less than the speeds observed on the roadways with wider shoulders. Roadways with curb and gutter had speeds across the entire range seen on roadways with shoulders (25 to almost 60 mph). There is no evidence that the presence of curb and gutter results in lower speeds for a facility. On highways with wide shoulders speed limit affected more the upper than the lower speeds, whereas on highways with wide pavements speed limit affected the speeds more at the lower end of the distribution (Fitzpatrick et al, 2003).

The relation between design speed, operating speed, and post speed has been presented in the table below (Fitzpatrick et al, 2003).

Table 3: The relation between design, operating and posted speed **(**Fitzpatrick et al, 2003)

Rural Road					
Terrain	**Speed terms**	**Two lane**		**Multilane highway**	
		Low	**High**	**Dived**	**Undivided**
Level /rolling	Anticipated operating speed (mil/h)	35-55	60-65	60-65	60-70
	Posted speed(mil/h)	55	55	55	65
	Design speed (mil/h)	60	60	60	60-70
Mountainous	Anticipated operating speed (mil/h)	35-55	30-60	50-60	50-60
	Posted speed(mil/h)	25-35	55	45-55	50-60
	Design speed (mil/h)	30-40	35-60	50-60	50-60

In the above table 3, anticipated operating speed is greater than posted speed limit. Free Flow Speed is best measured at the site or at a similar site.

To summarize, the basis for the most scientific researches which mentioned here in the above is the concept of Highway Capacity manual (HCM) that published in different reactive years. Most researcher preferred the HCM to perform the level of service analysis in different juncture.

2.3.2. Level of Service Practice in East Africa Community

In Africa especially in East Africa Community that comprising the countries such as Burundi, Kenya, Rwanda, Tanzania and Uganda, have developed a manual and guideline for selection of design levels of service, for the different classes of roads and to guide all country members of the region in their design. The purpose of this manual is to get harmonized road network in the region so that a well-balanced, economical road system will result. This manual refers on American standards HCM and AASHT (Uwitonze, 2014). The HCM was chosen because it is the best practice, are feasible by using available data (field data) and some default data where field data are not available.

LOS practice in East Africa regions has been advanced in a way that the country members have guidelines for selection of design levels of service for the different classes of rural roads and there are design manuals for the region Partner States in which all those parameters are given (Uwitonze, 2014). However, the level of service given in the manual varies between the roadway geometric design guides. The design guide for Uganda suggests design levels of service for rural roads for a given combinations of road functional class, road design class and terrain. Table 4 shows the East African region LOS while levels of service selection guidelines are missing in the design guides for Kenya and Tanzania. East Africa Community has been recommending adopting guidelines shown in following table 4 for the selection of design levels of service for the different road classes.

Table 4: Proposed guidelines for selection of design LOS in East Africa Community (Uwitonze,2014)

Level of Service (LOS) for specified Combinations of Terrain and Area Type					
Function	**class**	**Level terain**	**Rolling terrain**	**Mountainous terain**	**Steep terrain**
Mobility Roads	Class 1	B	B	C	C
	Class 2	B	C	D	D
	Class 3	B	C	D	D
Access roads	Class 4	D	D	D	D
	Class 5	D	D	D	D

Once a level of service has been identified as applicable for design, the accompanying service flow rate logically become the design service flow rate, implying that if the traffic flow rate using the facility exceeds that value, operating conditions will fall below the level of service for which the facility was designed. Once a level of service has been selected, it is desirable that all elements of the roadway are consistently designed to this level. Design service flow rate is the maximum hourly flow rate of traffic that a project road of designed dimensions would be able to serve without the degree of congestion falling below a pre-selected level of service. The objective in road design is to create a facility with dimensional values and alignment characteristics such that the resulting design service flow rate (design capacity) is at least as great as to the traffic flow rate during the peak 15-minute period of the design hour, but not enough greater as to represent extravagance or waste (Uwitonze, 2014).

Table 5: Selection of LOS for rural roads in Uganda (Uwitonze, 2014)

Road functional class		**Level of Service (LOS)**			
		Level terain	**Rolling terrain**	**Mountainous terain**	**Road design class**
A	International truck roads	B	B	C	Paved Ib,II and III paved
B	National truck road	B	C	D	Ib, II and III paved, A gravel
C	Primary roads	C	D	D	II and III paved, A gravel
D	Secondary Roads	D	D	E	A and B gravel
E	Minor roads	E	E	E	II and III

In this research, the researcher has exhaustively searched the literature related to Level of Service analysis in Ethiopia and found that so far no published document and guideline, which is used to analysis level of service in terms of letter scheme A to F for two-lane, two-way roads. Thus, the researcher prefers to perform this research using methodology that out line in highway capacity manual 2010, which published recently and analysis shall be carried out using the software that developed based on the models in this manual.

2.4. Method of Speed Study

Radar-Gun Methods: - Radar-gun is a commonly used device for directly measuring speeds in spot speed studies. This device may be hand-held, mounted in a vehicle, or a mounted on tripod. The effective measuring distance for radar meters ranges from 200 feet to 2 miles (Parma, 2001). A radar meter requires line of-sight to accurately measures speed and operates by one person.

Different sized vehicles and the detection of the observation vehicle may affect radar readings (Currin, 2001). Large vehicles such as trucks and buses send the strongest return signal to the radar meters and as a result, smaller vehicles may not be detected. If there is a presence of large vehicles, the observer may need to record the speeds of vehicles that are alone. In addition, some vehicles are equipped with radar detectors to warn them that a radar unit is operating in their vicinity. Drivers will slow down when warned by a detector. It is usual for other drivers to slow down speed. This slowing will affect the study results.

CHAPTER THREE

RESEARCH METHODOLOGY

This section of the research addressed the Input data requirement for this thesis, models used in HCS 2010 to estimate FFS, demand, ATS and PTSF for the analysis of LOS in each direction of the lane and analysis of LOS with passing lane. Method of data collection used for this research has been also discussed in this section. The analysis of LOS for each direction of lane with and without passing lane performed using HCS 2010 software.

The Highway Capacity Software (HCS2010) implements and automates the HCM procedures. The procedures detailed in the current version of the Highway Capacity Manual (HCM 2010) estimate capacity and several operational measures dictating level of service for freeway facilities, two lane, facility, multilane, ramp and roundabout as well as surface streets (Lily .E. and Michael A.,2016). HCS 2010 provide interface by activating the main menu and all modules. The interface for each module is functions, report future.

3.1. Models Used for the Analysis of LOS

The analytical procedure provided in HCM 2010 applies for operation and planning of the two-lane, two-way highways. The researchers in different institutions refers to the Highway Capacity Manual (HCM), as the only best practice which has been improved or edited since 1950 and every time, a new edition came with new improvement of the manual (HCM). Hence, operational analytical procedures for two-way, two-lane highways, which set in the HCM 2010, has been adopted for this research to analysis the LOS using the data observed /measured from field which selected particularly for this study and default value from the manual as an input in the HCS 2010 software.

Highway Capacity Software (HCS 2010) developed and maintained by Mc Trans as part of its user supported software maintenance as a faithful implementation of the HCM procedures. HCM 2010 is a basis for the development of HCS 2010 Software for all capacity and level of service commutation (htt://mctrans.ce.ufl.edu/).

The data collected from field, collected from related origination and default values set in HCM 2010 used as input data in the software described in detail as below.

3.1.1. Data and Models Used in HCS 2010

The most important data required as an input in HCS 2010 to analyze the LOS of two-lane, two-way roads mainly categorized as geometric data and demand data. The geometric data includes highway class, lane width, and shoulder width, access point density, and terrain, percentage of no-passing zone, speed limit, and base design speed. Under categories of demand, the most appropriate data required are hourly volume, length of the analysis period, peak hour factor directional split, and heavy vehicle percentage. Among those data highway class and hourly volumes are critical data and must be site specific (HCM, 2010).

In this study, the researcher has used data measured in the field, obtained from ERA traffic count as an input in HCS 2010 and the default value which recommended by HCM 2010 in order to analyze the LOS for selected two-lane, two-way road for this particular study. The figure 3 below shows the summery of basic input data, models used in HCS 2010 and the procedures to analysis the LOS.

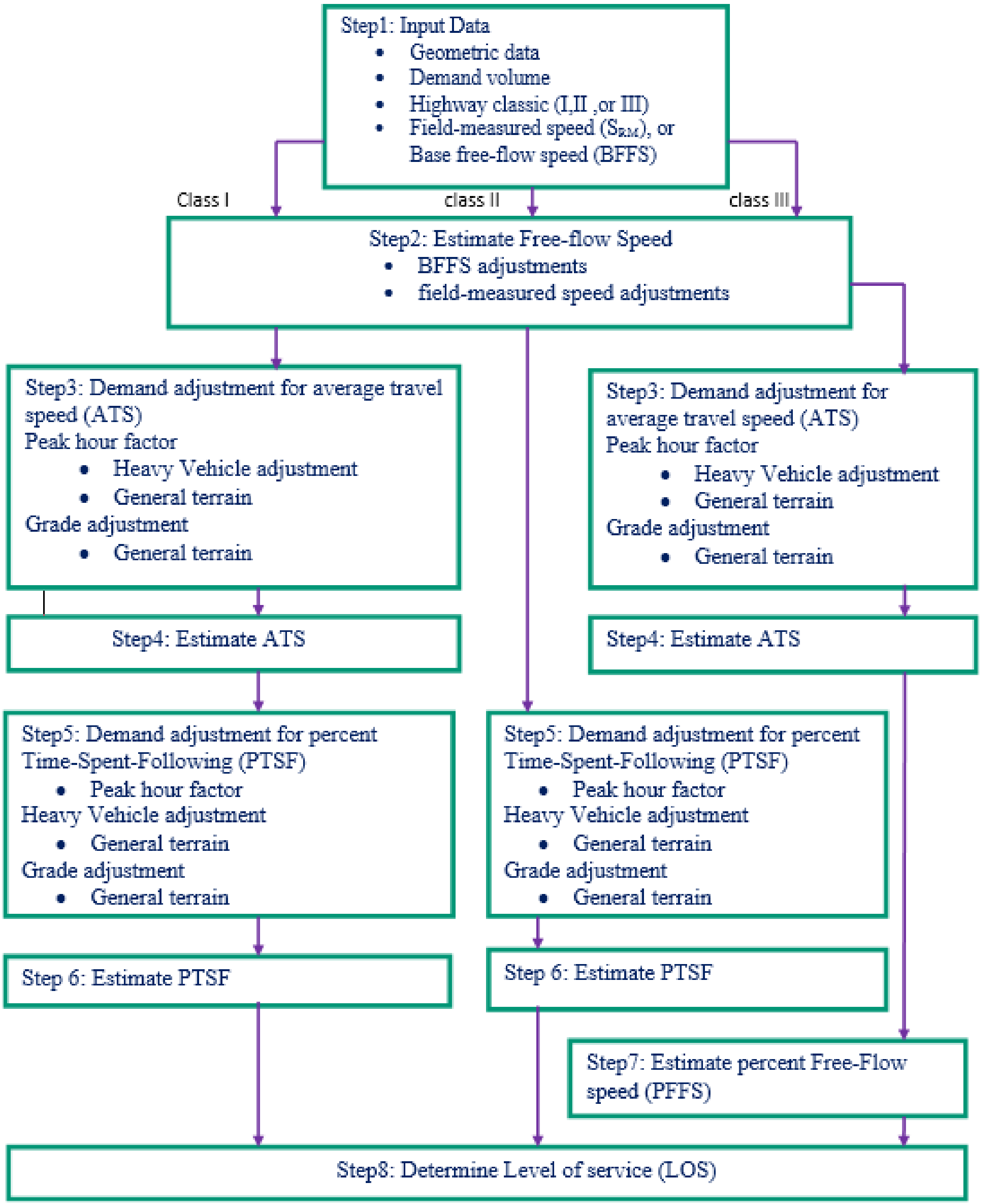

Fig 5: Procedural Step of LOS analysis

3.1.1.1. Demand

The most important demand data required for the analysis of LOS are hourly volume of passenger car (veh/h), length of analysis period (i.e.15min), peak hour factor (PHF), directional split and heavy vehicle percentage. Traffic demand is the principal measurement of the amount of traffic for the analysis of two-lane, two-way roads. In traffic analysis, traffic demand (Veh/h) includes vehicles arriving volume, directional volume (Veh/h) opposing and both directional volume (Veh/h). Traffic demand also summarized as Average Daily Traffic (ADT) including motorcycles and from those volumes, percentage of heavy vehicles (HVs) and buses as well as recreational vehicles (RVs) are determined (HCM,2010).

The design hourly volume (DHV) for rural highways should generally be the 30 HV of the future year chosen for design. On a typical rural arterial, the 30 HV is about 15 percent (15%) of the Average Daily Traffic (ADT), and the maximum hourly volume is about 25 percent of the ADT (AASHTO, 2001).

Ethiopian Road Authority (ERA) design manual 2013 has explained that for a two-lane, two-way roads of flat terrain, the capacity reached when the traffic level (sum of both directions) approaches 3,200 and 1,700 for 1-direction equivalent passenger cars per hour. The manual also has stated that the peak hour volume (vehicle per hour) is usually between 12 to 18 percent of ADT and a value 15 percent is reasonable average. ERA has counted the ADT and AADT in a three season, in every year in different station for all already constructed Federal highway. As this research has done for Federal 2-lane, two-way roads segment, adopting ERA traffic count for peak hour is ideal. Hence, for the LOS analysis of two-way segment and analysis direction, this study has considered demand volume for the full peak hour as 15 percent of Average Daily Traffic (ADT) of ERA traffic Count first cycle of 2017.

Peak-Hour Factor: The Peak Hour Factor (PHF) uses to convert the rate of flow during the highest 15 – minute period to the total hourly volume or vice-verse. In Highway Capacity Manual, PHF considered as operating conditions during the most congested 15 – minute period of the hour to establish the service level for the hour as a whole. It also be described as the ratio of the total hourly volume to the number of vehicles during the highest 15-minutes period multiplied by 4 (hourly volume dived by four multiplied by peak 15-minute volume.

As stated in HCM, the ratio of hourly demand to four times the peak 15-min demand is never greater than one and typically ranges from 0.75 to 0.95. The higher values tend to occur as demand approaches capacity on the facility. Default values of 0.88 for rural areas and 0.92 for urban areas may utilize in the absence of local data (HCM, 2010). Thus, due to absence of appropriate field data, this research has considered the peak hour factor as 0.88 as this research has done on to two-lane, two-way roads in the rural area.

Directional Split: Directional distribution defined as 50/50 for base conditions. Most directional distributions on rural two-lane highways range from 50/50 to 70/30. On recreational routes, the directional distribution may be as high as 80/20 or more during holiday or other peak periods (HCM, 2000). If field observed data are not available, default directional splits values used, which mentioned in direction split table lists of HCM, 2000.

Table 6: Directional split from (HCM, 2000)

Type	Directional split
Rural Highway	60/40
Urban Highway	60/40
Recreational Highway	80/20

However, HCM 2010 LOS analysis procedure is for both direction separately. Hence, directional split has no effect in the LOS analysis using HCM 2010.

Heavy Vehicle Percentage: Heavy vehicles are a common feature of traffic flow on the roads as the movement of freight all over the country depends more on the road by using those heavy vehicles. During determination of passenger-car equivalents and computation of heavy vehicle adjustment factor, if the relative proportions of RVs, trucks, and buses are not well known, then the trucks will be consider as heavy vehicles (HCM, 2000). Default percentage value of heavy and recreational vehicles shown in the table below.

Table 7: Percentage of heavy vehicle from (HCM, 2000)

Type of vehicle	Rural (%)	Urban (%)
Truck (including buses)	14	2
RVs	4	0

In the absence of local data, a default value from table of HCM 2010 may be used. However, this study used percentage of heavy vehicles by averaging of 14 years ERA traffic count data, which counted from 2002 to 2017.

Average Daily Traffic (ADT), which collected from ERA traffic count from 2002 to first cycle of 2017, shows that the average proportion of heavy vehicle including large buss are:

- 52 percent for both Addis Ababa to Sendafa and Sendafa to Addis Ababa,
- 50 percent for Sululta to Chancho road and 52 percent Chancho to Sululta
- 45 percent for both Sebeta to Tulubulo and Tulubulo to Sebeta road

3.1.1.2. Geometric Data

For the analysis of LOS of two-lane, two- way highway, lane width, shoulder width, access point density (one side), percent of no-passing zone, speed limit, base design speed, highway class (must select as appropriate), and passing lane (if present) are the most important geometric data.

In this study, highway class considered as class-I, since, the study has done on the two-lane, two-way roads, which connect the Addis Ababa City to the nearby town at a level terrain. Particularly, this study has done by taking the 5 km Segment between Sebeta-Tulubulo, between Sululta-Chancho and between Addis Ababa-Sendafa as the motorists expect to travel at relatively high speed on this route.

As measured in field, the lane and shoulder width are 3.5m and 1.5m respectively for the roads segment selected for this study. In the selected road segment, there is no access point and no- passing zone. As result, for zero access point and zero no-passing zone, the access point density and percent of no-passing zone is determined as shown in the HCM, 2010 manual.

3.1.1.3. Models Used for HCS 2010 to Analyze ATS

One of the most critical needs in traffic engineering is a clear understanding of how much traffic for a given facility can accommodate and under what operating conditions. These important issues addressed in highway capacity and level of service analysis. For the analysis of the capacity and LOS, the analytical procedures are set out in different edition of HCM, which published by Transport Research Board (TRB) of the American National Academy of Engineering. These analytical procedures relate the demand or existing flow level to the geometric characteristics of the road and control the measurement of the resulting quality of operations. TRB published different HCM in several times for the analysis of LOS. Among this, HCM 2010 is more appropriate and recent edition for the analysis of LOS for two-lane, two-way roads in the rural area. Some Modification has incorporated in HCM 2000 and HCM 2010 developed for the analysis of LOS of two-lane, two-way roads segment that include the town section in the analysis.

Level of Service (LOS) defined in terms of effective measurement of Average Travel Speed (ATS) and Percent Time Spent Following (PTSF). Average Travel Speed (ATS) is the average speed of analysis segment for the specified times of traffic flow, which is usually the peak 15-minutes of a peak hour. In the case of analysis of LOS for both directions of traffic flow based on HCM 2000, the ATS calculation should include vehicles in both directions whereas for the analysis of single direction, the ATS includes those vehicles in the analysis direction only. However, the analysis of LOS based on HCM 2010 carried out for both direction of flow of traffic in two-lane two-way separately.

Determination of LOS for two-lane, two-way of Class-I highway in the directional segments in the HCM, 2010 procedure, are based on both PTSF and ATS whereas determination of LOS for two-way, two-lane of Class-II highway segments are based on PTSF only. Average Travel Speed can be determined by using the following Equation 1.

$$ATS_d = FFS - 0.00776\left(V_{d,ATS} + V_{o,ATS}\right) - f_{np,ATS} \qquad \text{Equation 1}$$

$$where\ ATSd = Averege\ Travel\ speed\ in\ the\ analysis\ directon\ mil/h$$

$$FFS = Free\ Flow\ Speed\ mil/h$$

$$V_{d,ATS} = demand\ flow\ for\ ATS\ determination\ in\ the\ analysis\ direction\ (pc/h)$$

$V_{o,ATS} = demand\ flow\ for\ ATS\ determination\ in\ the\ opposite\ direction\ (pc/h)$

$f_{np,ATS}\ = Adjustment\ factor\ for\ ATS\ determination\ for\ the\ percentage\ of$

$no\ passing\ zone\ in\ the\ analysis\ direction\ from\ EXHIBIT\ 15-15\ of\ HCM\ 2010$

3.1.1.4. Models Used for HCS 2010 to Analyze FFS

Free-flow speed (FFS) determination is the first step in the analysis of level of service. There are three ways to estimate FFS (HCM, 2010). Each FFS measurement method described as below

Direct Field Measurement: - Direct field measurement on the subject highway segment is preferred. If both directions analyzed, then separate measurements in each direction made. Each directional measurement based on a random sample should be at least 100 vehicle speeds. The FFS can be directly measured as the mean speed under low-demand conditions (i.e., the two-way flow rate is less than or equal to 200 veh/h). If the analysis segment can not be directly observed, then measurements from a similar facility (same highway class, same speed limit, similar environment, etc.) may be used (HCM, 2010).

Field Measurements at Higher Flow Rates:-For some highways, it may be difficult or impossible to observe total flow rates less than 200 veh/h. In such cases, a speed sample might take at higher flow rates and adjusted accordingly. The same sampling approach has taken in each direction separately observed, with each directional sample including at least 100 observed speeds. The measured mean speed then adjusted with Equation 2:

$$FFS = S_{FM} + 0.00776\left(\frac{v}{f_{HV,ATS}}\right) \qquad Equation\ 2$$

$where\ FFS = free\ flow\ speed\ (mil/h)$

$S_{FM} = mean\ speed\ of\ sample\ (v > 200veh/h)(\ mil/h)$

$v = total\ demand\ flow\ both\ direction\ during\ period\ of$

$speed\ measurment (veh/h)$

$f_{HV,ATS} = heavy\ vehicle\ adjustment\ factor\ for\ ATS$

Estimating FFS:-The FFS can also estimate indirectly if field data are not available. This is a greater challenge on two-lane highways than on other types of uninterrupted-flow facilities. FFS on two-lane highways covers a significant range, from as low as 45 mil/h to as high as 70 mil/h. To estimate the FFS, the analyst must characterize the operating conditions of the facility in terms of a BFFS that reflects the nature of the traffic and the alignment of the facility (HCM, 2010).

Estimates of BFFS can develop based on speed data and local knowledge of operating conditions on similar facilities. As will be seen, once the BFFS is determined, adjustments for lane and shoulder widths and for the density of un-signalized access points apply to estimate the FFS. A rough estimate of BFFS might take as the posted speed limit plus 10 mil/h. Once a BFFS is determined, the actual FFS can estimate as follows Equation 3 below.

$$FFS = BFFS - F_{LS} - F_A \qquad Equation\ 3$$

$$where\ FFS = Free\ Flow\ Speed\ (mil/h)$$

$$BFFS = Base\ Free\ Flow\ Speed\ (mil/h)$$

$$fls = Adjustment\ for\ lane\ and\ shoulder\ width$$

$$fA = Adjustment\ for\ Acces\ point$$

In this study, the free flow speed estimated based on speed of vehicle, which measured in the field using radar gun for the sample vehicle taken in which the flow of traffic greater than 200 vehicle per hour.

3.1.1.5. Heavy Vehicle Adjustment Factor (f_{HV})

Heavy vehicle adjustment factor can be determined using the formula

$$f_{HV,ATS} = \frac{1}{1+PT(ET-1)+PR(ER-1)} \qquad \text{Equation 4}$$

$$where\ f_{HV,ATS} = heavy\ vehicle\ adjustment\ factor\ for\ ATS\ estminate$$

$$PT = proportion\ of\ trucks\ in\ the\ traffic\ stream$$

$$PR = proportion\ of\ RVs\ in\ the\ traffic\ stream$$

$$ET = passsanger - car\ equivalent\ for\ trucks\ from\ EXHIBT\ 15-11$$
$$or\ EXIHIBT\ 15-12\ of\ HCM\ 2010$$

$ER = passanger - car\ equivalent\ for\ RVs\ from\ EXHIBT\ 15 - 11$
$or\ EXIHIBT\ 15 - 12\ of\ HCM\ 2010$

3.1.1.6. Model Used for HCS 2010 to Analyze Demand Volume

This computational step applies only in the case of Class I and Class III two-lane highways. LOS on Class II highways is not on basis of ATS. Demand volumes in both directions (analysis direction and opposing direction) must convert to flow rates under equivalent base conditions with Equation 5.

$$V_{i,ATS} = \frac{V_i}{PHF * f_{g,ATS} * f_{HV,ATS}} \qquad Equation\ 5$$

$Where\ V_{i,ATS}$ = demand flow rate i for ATS estimation (PC/h)

V_i = demand volume for a direction i (veh/h)

i = "d" (analysis direction or "o" (opposing direction)

$f_{g,ATS}$ = grade adjustment factor , from EXHIBIT 15-9 or EXHIBT 15-10

$f_{HV,ATS}$ = heavy vehicle adjustment factor, from Equation 4

There are two types of grade adjustment factors, which are used in the analysis of LOS. They are grade adjustment factor to be used for the determination of average travel speed and grade adjustment factor to be used for the determination of percent time spent following. Grade adjustment factor to be used to determine speeds are given in EXHIBIT 15-9 of HCM2010, and those to be used to determine percent time spent following are given in EXHIBIT 15-10 of HCM 2010.

Passenger car equivalents for determining f_{HV} also depend on whether ATS or PTSF is being determined; those in determining ATS has given in EXHIBIT 15-9 and those in determining PTSF has given in EXHIBIT 15-10 of HCM, 2010. For both fG and f_{HV} determination the value ET and ER depend on the flow rate (Vp); consequently, iterative calculations are required to find Vp.

The procedure for calculating Vp is being began by setting Vp equal to V/PHF. Then, using the appropriate values of f_G, E_T, and E_R calculate a new value for Vp. If this is outside the flow limits for which f_G, E_T, and E_R were calculated, recalculate Vp with new values of f_G, E_T, and E_R required and iteration process continued. This process continues until the value of Vp is consistent with the flow ranges assumed in choosing f_G, E_T, and E_R *(HCM, 2010)*.

3.1.1.7. Models Used for HCS 2010 to Analyze PTSF

The percent time-spent-following is being determined from the demand flow rate, the directional distribution of traffic, and the percentage of no-passing zones. The demand flow rate (vp) for estimating percent time-spent-following is determined with Equation-6 using the value of f_{HV} computed with passenger-car equivalents from EXHIBIT 20-10 of HCM2010. The Percent time spent following is being computed by the following formula.

$$PTSF_d = BPTSF_d + f_{np,PTSF}\left(\frac{V_{d,PTSF}}{V_{d,PTSF}+V_{o,PTSF}}\right) \qquad Equation\ 6$$

$where\ PTSF_d = percent\ time\ spent - following\ in\ the\ analysis\ direction$

$BPTSF_d\ = base\ percent\ time\ spent - following\ in\ the\ analysis$
$direction\ from\ Equation\ 9$

$f_{np,PTSF} = adjustement\ to\ PTSF\ for\ the\ percentage\ of no - passing\ zone$
$in\ the\ analysis\ segment\ from\ EXHIBIT\ 15-21\ of\ HCM\ 2010$

$V_{d,PTSF}$ = demand flow rate in the analysis direction for estimation of PTSF (pc/h);

$V_{o,PTSF}$ = demand flow rate in the opposing direction for estimation of PTSF (pc/h)

3.1.1.8. Demand Volume Adjustment for PTSF Determination

The demand volume adjustment for estimating PTSF is structurally similar to that for ATS. The general approach is the same, but different adjustment factors are used, and the resulting adjusted flow rates will be different from those used in estimating ATS. Therefore, a detailed discussion of the process is not included here, since it is the same as that described for ATS estimates.

$$V_{I,PTSF} = \frac{Vi}{PHF * f_{g,PTSF} * f_{HV,PTSF}} \quad \text{Equation 7}$$

$$f_{HV,PTSF} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} \quad \text{Equation 8}$$

$where\ V_{i,PTSF} = demand\ volume\ rate\ i\ for\ determintion\ of\ PTSF(PC/h)$

i = " d"($analysis\ direction$) or "o"($opposite\ direction$)

$f_{g,PTSF}$ = grade adjustment factor for PTSF determination, from EXHIBIT 15-16 or EXHIBT 15-17 of HCM 2010

$f_{HV,PTSF}$ = heavy vehicle adjustment factor for PTSF determination, from EXHIBIT 15-18 or EXHIBT 15-19 of HCM 2010

The base percent time-spent-following (BPTSF) applies to base conditions and estimate by Equation9:

$$BPTSF = 100\left[1 - \exp\left(aV_d{}^b\right)\right] \quad Equation\ 9$$

Where a *and* b are constants drawn from HCM 2010 and all other terms are as previously defined and are entered with demand flow rates fully converted to passenger cars per hour under base conditions (v_o and v_d)

3.1.2. Computation of LOS

The first step in determining level of service is to compare the passenger-car equivalent flow rate (V_d) to the road way capacity of 1,700 pc/h. If V_d is greater than the capacity is oversaturated and the LOS is F. In LOS F, percent time-spent-following is nearly 100 percent and speeds are highly variable and difficult to estimate (HCM, 2010).

Finally, after determination of all the input data required and models used for HCS 2010 software LOS analysis performed using this software. Detail analysis shown in the analysis part of this thesis

3.1.3. Determination of LOS for Directional Segment with Passing Lane

In the ERA 2013 design Manual, the passing point is included in the carriageway of road as additional safety and miscellaneous items. This is because single lane roads do not allow vehicles to pass in opposite directions or to overtake. A passing point is a short length of widened road with a taper at each end (ERA Manual, 2013). It appears similar to an elongated bus stop or a lay bay. The structure and surface of the passing point is the same as the main carriageway. The increased width provided by passing place should allow two vehicles to pass at slow speed and depend on the design vehicle.

The frequency of provision of passing point in the Federal roads of Ethiopia depends up on the following factor

- Meeting site distance
- Traffic volume and mix
- Acceptable reversing distance for vehicles
- Terrain
- Strength of surrounding ground

In hilly terrain, the spacing of passing point must be more flexible and responsive to both sight distance and the construction of the surrounding landscape. Drivers of heavy or wide vehicles may be unwilling to reverse long distance where trucks are travelling in both, it may be necessary to reduce passing point spacing .After determining the spacing and location of passing point, the length and width should be set. The length is primarily depending on the traffic volume (ERA Manual, 2013)

Table 8: Length (including tapers) of passing point (ERA, 2013)

Traffic volume(vehicle per day)	**Length of passing point(m)**
<20	25
20 to 30	50
More than 30	75

A suitable width depends upon the width of the roads itself. The criterion is to provide enough overall width for two design vehicles to pass each other safely at low speed hence a total trafficable minimum width of 5.5 meters is required. Allowing vehicle overhang, when entering the passing bay, a total width of 6.5 meter is suitable.

However, passing point length described in ERA design manual is very short for all condition of the flow more than 30 vehicle per day compared to the minimum length of passing lane to the other countries which uses passing lane for the improvement of the performance of two-lane highway.

The first step in the operational analysis of a passing lane is to apply the procedure for directional segments in level or rolling terrain to the normal cross section without the passing lane. The data required are the demand volume in the analysis direction, demand volume in the opposing direction, vehicle mix, lane width, shoulder width, and percentage of no-passing zones. The result is the percent time-spent-following and the average travel speed for the normal two-lane cross section (HCM, 2010).

The next step is to divide the analysis segment into four regions. These regions are:

- Upstream of the passing lane
- the passing lane
- Downstream of the passing lane but within its effective length, and
- Downstream length of the passing lane but beyond its effective length.

These four lengths must add up to the total length of the analysis segment. The analysis regions and their lengths will for estimations of percent -time- spent- following and average travel speed, because the downstream lengths for these measures different, as shown in EXHIBIT 20-23 of HCM 2010.

The length of the passing lane, Lpl, used in the analysis, is either the length of the passing lane as constructed or its planned length. However, in this study the length of passing lane, Lpl is the planned lengths. The passing lane length should include the lengths of the lane addition and lane drop tapers. Passing lane lengths substantially shorter or longer than the optimum may provide less operational benefit than predicted by this procedure. The length of the conventional two-lane highway segment upstream of the passing lane, Lu, is determined by the actual or planned placement of the passing lane within the analysis section (HCM, 2010).

However, in the location where this study performed provided passing lane is not available and hence the segment upstream of passing lane Lu, determined based on planed placement of the passing lane. In this study, passing lane proposed as the improvement mechanism of LOS for the selected two-lane, two-way roads. LOS of two-lane, two-way roads analyzed using HCS 2010 software with and without passing lane to simulate either LOS improved or not.

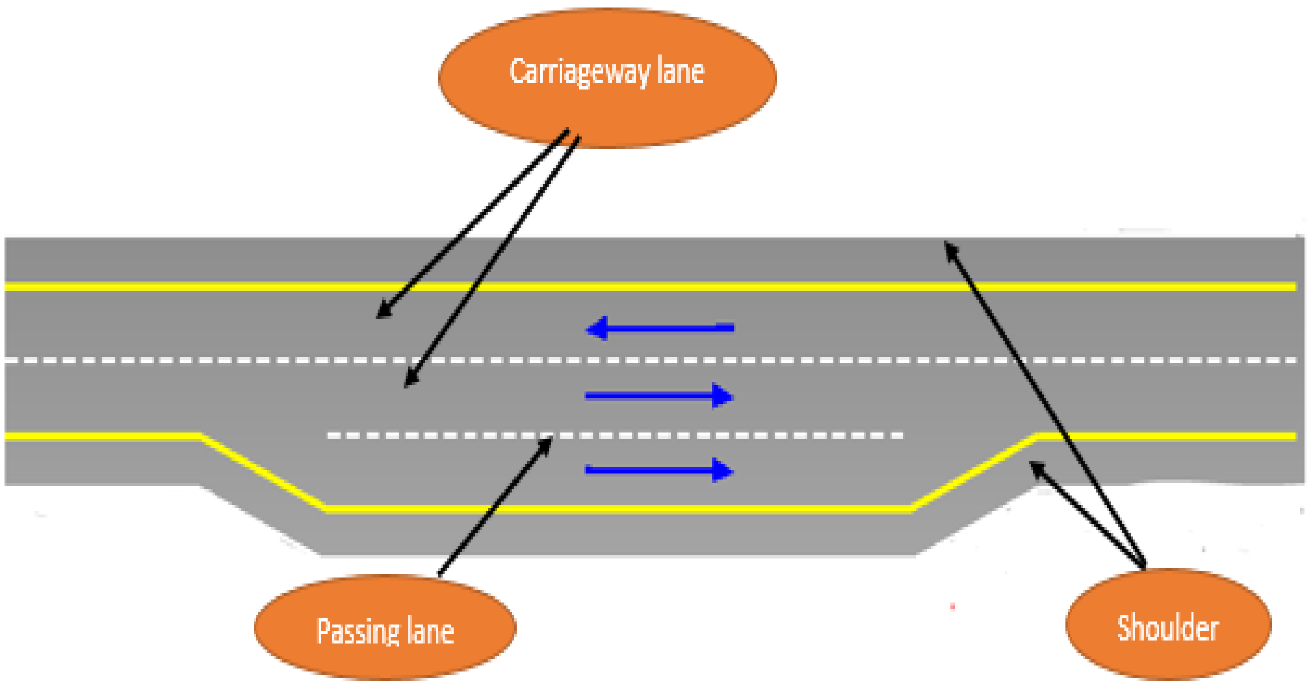

Fig 6: passing lane layout

Length of Analysis Segment

$$Ld = Lt - (Lu + Lpl + Lde) \qquad Equition\ \ 10$$

$where\ Ld$: $Length\ of\ two-lane\ highway\ downstream\ of\ the\ passing\ lane$

$and\ beyond\ its\ effective\ length\ \ (Km)$

Lt: $total\ length\ of\ analysis\ segment\ \ (Km)$

Lu: $length\ of\ two-lane\ highway\ upstream\ of\ the\ passing\ lane\ (Km)$

$Lpl: length\ \ of\ the\ passing\ lane\ including\ taper\ lane\ \ (Km)$

$Lde: downstream\ length\ of\ two-lane\ highway$

$with\ effective\ length\ \ of\ the\ passing\ lane$

$(Km)(from\ EXHIBIT\ 20-23\ of\ HCM)$

3.1.3.1. Model Used for HCS 2010 to Analyze ATS with Passing Lane

Average travel speed within length Lu and Ld is assumed to equal ATSd as predicted by the directional segment procedure. Within the passing lane, average travel speed is generally 8 to 11 percent higher than its upstream value. This effect varies as a function of directional flow rate as shown in EXHIBIT 20-24 of HCM 2000. Within the downstream length (Lde), average travel speed is assumed to decrease linearly with distance from the within passing -lane value to its normal upstream value. Thus, the average travel speed with the passing lane in place computed using Equation 10 below.

$$ATS_{pl} = \frac{ATS_d L_t}{L_u + L_d + \left(\frac{L_{pl}}{f_{pl,ATS}}\right) + \left(\frac{2L_{de}}{1+f_{pl,ATS}}\right)} \qquad Equation\ 11$$

$where\ ATSpl = average\ travel\ speed\ for\ the\ analysis\ \ segment\ affected\ by\ passing\ lane$
(mIl/h)
$ATSd = average\ travel\ speed\ for\ the\ entire\ segment\ without$
$the\ passing\ \ lane\ from\ equation\ \ (mil/h)$
$f_{pl,ATS} = adjustment\ factor\ for\ \ the\ effect\ of\ \ passing\ \ lane\ on\ ATSd$
$from\ EXHIBIT\ 15-28\ of\ HCM\ 2010$

3.1.3.2. Model Used for HCS 2010 to Analyzed PTSFd with Passing Lane

PTSF within lengths L_u and L_d is assumed to be equal to the $PTSF_d$ as predicted by the normal analysis procedure (without a passing lane). Within the segment with the passing lane L_{pl}, PTSF is generally equal to 58% to 62% of its upstream value. This effect is a function of the directional demand flow rate. Within L_{de}, the PTSF assumed to increase linearly from the passing lane value to the normal upstream value. This distribution illustrated in (HCM, 2010). Thus, the average percent time- spent- following with the passing lane in place computed using Equation 11.

$$PTSF_{pl} = \frac{PTSF_d\left[L_u + L_d + f_{pl,PTSF}\, L_{pl} + \left(\frac{1+f_{pl,PTSF}}{2}\right) L_{de}\right]}{L_t} \qquad Equation\ 12$$

$where PTSF_{pl} = percent\ time - spent\ following\ for\ segment\ as\ affected\ by\ the$

$presence\ of\ a\ passing\ lane$

$PTSFd\ = percent\ time\ spent\ following\ \ for\ entire\ segment$
$without\ passing\ lane\ \ from\ equation\ 6$

$f_{pl,PTSF} = adjustment\ factor\ for\ impact\ \ of\ a\ passing\ \ lane\ on$

$percent\ time\ spent\ following\ from\ EXHIBIT\ 15 - 26$

$all\ other\ variables\ are\ as\ previously\ defined$

Table 9: Factor (fpl) for Estimation of ATS and PTSF (HCM, 2010)

Directional flow rate (pc/h)	**Average Travel Speed**	**Percent time spent following**
0-300	1.08	0.58
<3000-600	1.10	0.61
>600	1.11	0.62

3.2. Data Collection

The data required for this study are vehicle speed, lane width, shoulder width, analysis segment, AADT and ADT. Each data has been discussed in details as follows.

3.2.1. Study Area

The study site was located on a major two-lane, two-way Federal road of Ethiopia. Particularly, the study performed by taking 5 km segment on flat/level terrain of two-lane, two-way road of Addis Ababa to Sendafa, Sululta to Chancho and Sebetea to Tulubulo roads section. Lane and shoulder width for these road segments are 3.5 m and 1.5m respectively. Pavements for this segment are in good condition. All the sample data required for the analysis for this research has been taken from these road segments.

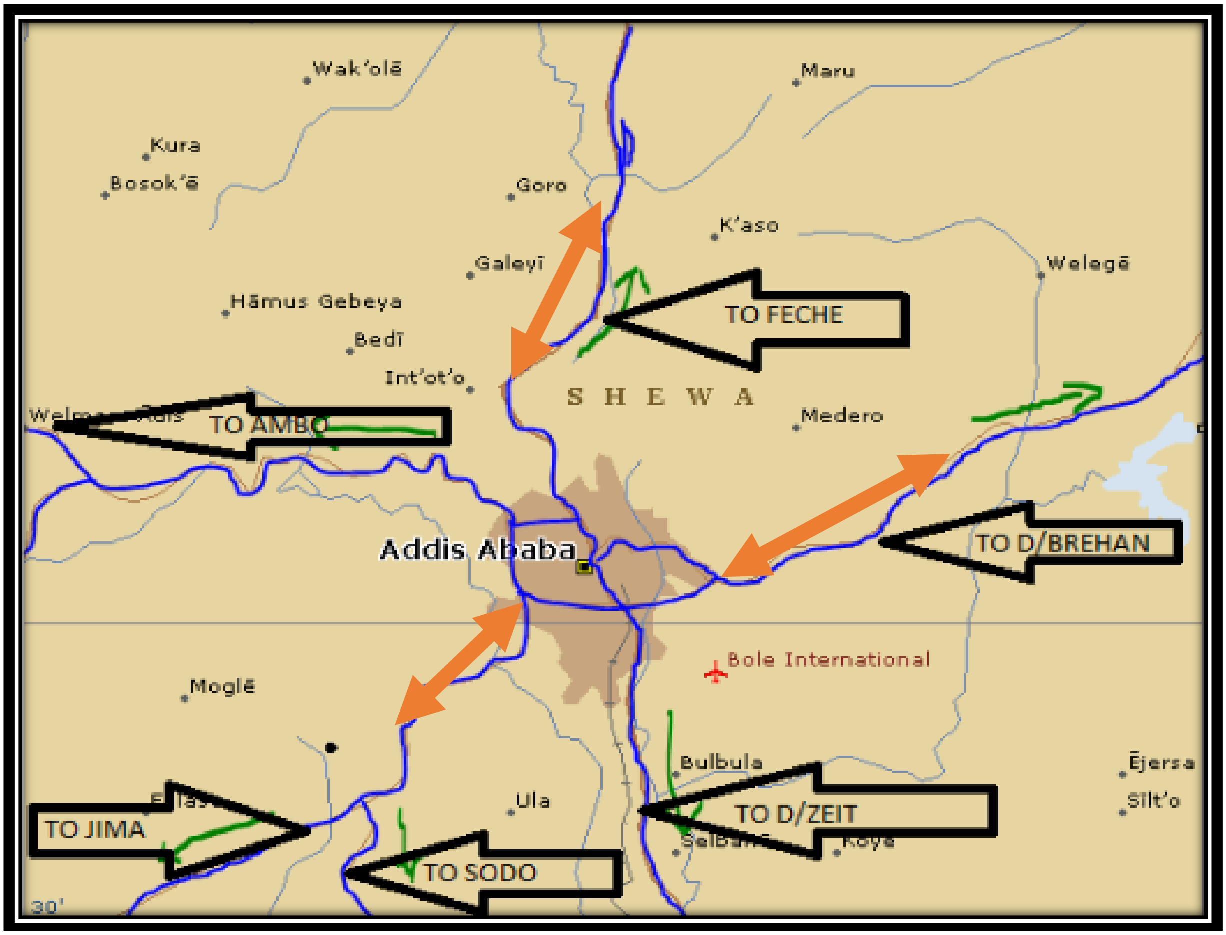

Fig 7: Map, which shows Study Area

3.2.2. Vehicle Speed

The individual vehicle speed can measure in different methods of speed measuring instrument such as stopwatch, radar gun, and video recording method etc. This study used the Radar-Gun, spot speed measuring device to measure the vehicle speed in the field.

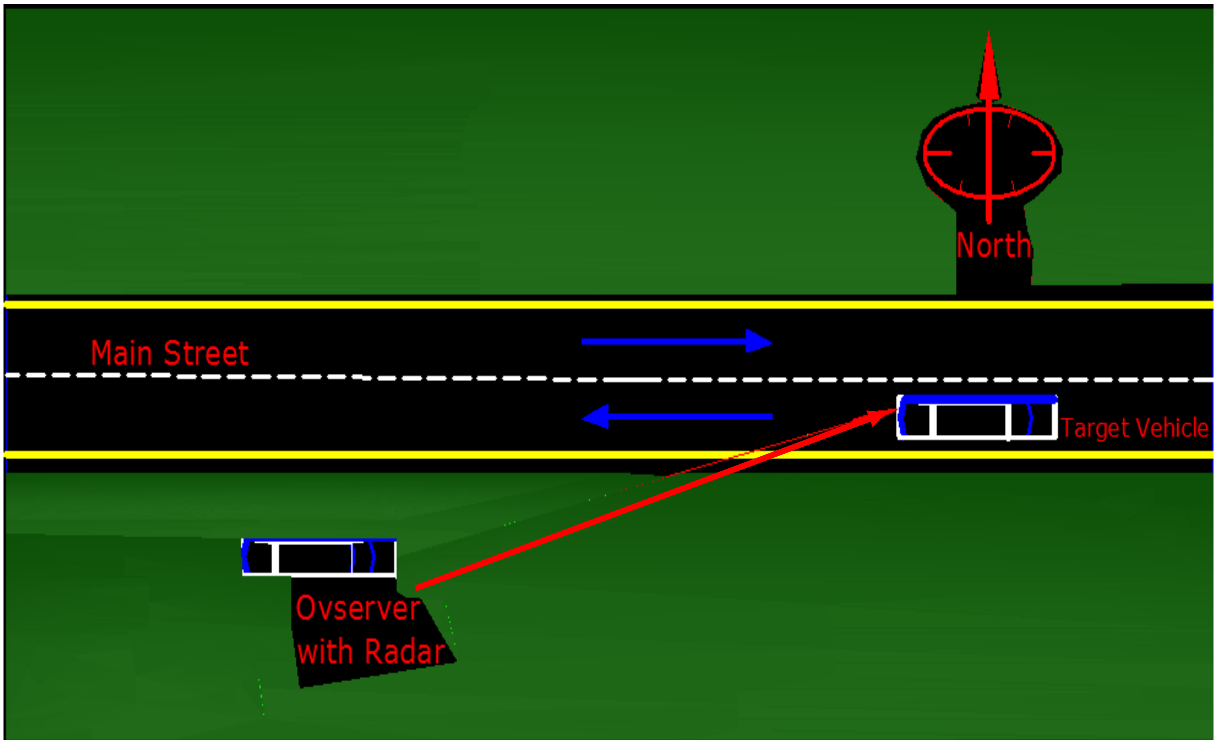

Fig 8: Radar Gun spot speed layout

The researcher used hand held radar-gun, which is available in Oromia Regional traffic office to measure the vehicle speed in the field of road segment selected for this study. The 5 km segment is located on the two-lane, two-way roads that selected for the purpose of this study to measure the speed of vehicle. The Selected roads for this study are Sululta- Chancho, Addis Ababa –Sendafa and Sebeta-Tulubolo. The surfaces of the roads are in good condition. Intersection and junction are not available within this 5 km roads segments. No-passing zone did not also observed on this selected road segment.

Before the speed measurement had done, the information about the traffic flow has gathered from the local traffic police and it has been noted that for all selected roads segment the traffic flow is relatively higher than 200 vehicle per hour after 7: 30 AM. In accordance with the information obtained, the team member counted the traffic for one hour in between 7:30 AM and 2:30 AM to make sure that the flow is higher in this period and found that the flow was higher than 200 vehicles per hour. The speed was measured in the month of May 2017.

Then, the researcher has requested permission the Chancho Worda Traffic polices to use radar gun and their technical assistance how to measure the speed of vehicle for those selected roads (i.e. Addis Ababa-Sendafa and Sululta-Chancho roads segment). After getting, the permission from Chancho Worda Traffic polices to use the radar-gun and assistance how to measure the vehicle speed, speed has measured via the team comprises two people; one person to record the vehicle speed in the already prepared sheet; another person to hold radar-gun. Traffic speed measured for the sample of 122 vehicles in one direction. The same procedure like Sululta-Chancho road segment followed to measure the speed of vehicle for 115-sample size in the 5 km road segment of Sebeta-Tulubulo and Addis Ababa -Sendafa.

It is the fact that the drivers reduce their speed while they seeing the traffic police. To avoid this effect, the speed measurement has made by the team without traffic police in the place. The speed measured during dry season to avoid cloud effect on the speed of vehicle. Sample of field measured speed shown in the table below. The detail speed measured using radar gun in the field is attached in the appendix of this paper.

The average speed of taken sample vehicles, which obtained from field measurement are:

- 80.0 km/h for 5 km segment of Sebeta-Tulubulo direction
- 80.4 km/h for 5 km segment of Tulubulo-Sebeta direction
- 76.78 km/h for 5 km segment of Sululta-Chancho direction,
- 77.9 km/h for 5 km segment of Chancho-Sululta direction and
- 81.26 km/h for Addis Ababa-Sendafa direction and 80.6 km/h for Sendafa-Addis Ababa direction.

3.2.3. Lane and Shoulder Width

The lane and shoulder width measured in the field using meter tape and found that 3.5 m for lane width and 1.5m shoulder width respectively for all selected road segments for this study.

3.2.4. Analysis Segment

The Analysis segments length are 5 km for all selected road segment for this study. The researcher selected the location of road segment by measuring the distance of 5 km using vehicle distance odometer on the flat terrain.

3.2.5. ADT and AADT

The researcher collected ADT and AADT from ERA traffic data recorded to analysis the flow of the traffic and traffic growth trends in the selected road segment. Details of ADT and AADT described as follows. The AADT defined as the total annual traffic summed for both directions and divided by 365. It usually obtains by recording actual traffic volumes over a shorter period from which the AADT estimated. Traffic counts carried out over a short period as a basis for estimating the AADT can produce estimates which are subject to large errors because traffic volumes can have large daily, weekly, monthly and seasonal variations. Traffic volumes vary more from day-to-day than from week- to-week over the year. Thus, there are large errors associated with estimating annual AADT from traffic counts of only a few days duration, or excluding the weekend. For this reason, there is a rapid decrease in the likely error as the duration of the counting period increases up to one week. For counts of longer duration, improvements in accuracy are less pronounced (ERA Manual, 2013).

Traffic volumes also vary from month-to-month (seasonal variation), so that a weekly traffic count repeated at intervals during the year provides a better base for estimating the annual volume of traffic than a continuous traffic count of the same total duration. Traffic also varies considerably through a 24-hour period. Traffic counts are for seven consecutive days. The counts on some of the days are for a full 24 hours with, preferably, at least one 24-hour count on a weekday and one during a weekend. On the other days, 16-hour counts should be sufficient. These extrapolated to 24-hour values in the same proportion as the 16-hour/24-hour split on those days when full 24-hour counts have been undertaken (ERA Manual, 2013).

In ERA, Countrywide traffic data collected on a systematic basis into three season to enable seasonal trends in traffic volumes to quantify AADT. The AADT used to obtain the growth rate and proportion of heavy vehicle for this study, collected from ERA traffic count record for the last 14 years. As recommended by ERA Manual 2013, the first cycle ADT of 2017, ERA traffic count used to obtain peak hour volume (i.e. 15% of ADT) for the analysis of LOS of the road segment with and without passing lane for the prevailing condition. The researcher has also used 15 percent of 2017 first cycle of ADT as peak hour volume to forecast the normal traffic for the future 20 years. The sample of ADT and AADT obtained from ERA traffic count has shown in the table below. Detail traffic count data for ADT and AADT attached in the annexure of this paper. Future ADT of each segment has been predicted by the following equation.

$$F = P(1 + I)^n \qquad Equation\ 13$$

$where\ F = forcasted\ ADT$
$p = present\ ADT$
$i = growth\ rate\ of\ ADT$
$n = analysis\ year$

The detail of data collected from ERA traffic count records for the selected road segments presented in the Appendix of this report.

The data collected from ERA traffic count record, the peak hour volume, average percentage of heavy vehicle and traffic growth rate were determined and summarized in the table 10 below.

Table 10: Peak hour volume, growth rate of vehicle & percentage of truck

road segment		Peak hour volume (15% of ADT for 2017 first cycle	Average Percentage of truck for 2002-2017)	growth rate ADT
From	To			
Addis Ababa	Sendafa	269	52	6%
Sendafa	Addis Ababa	279	52	6%
Sebeta	Tulubulo	328	45	6%
Tulubulo	Sebeta	354	45	7%
Sululta	Chancho	693	50	12%
Chancho	Sululta	677	52	11%

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Result and Discussion of LOS for Current Condition

The LOS has been analyzed for all selected road segment using HCS 2010 software for without and with passing lane scenario. The researcher has analyzed LOS of all selected road segment for both direction separately. The purpose of this analysis is to evaluate and know the quality of service for the prevailing condition of LOS for two-lane, two-way roads selected for this study.

For prevailing scenario without passing, all selected road segment being analyzed and operated with undesirable LOS between C and E. LOS between C and E means, passing demand, and passing capacity are unbalanced, the degree of platooning becomes noticeable, and the Speeds reduced prominently on the entire selected road segment. For all selected roads segment and for both direction platooning increases significantly in which passing demand is high, but passing capacity approaches zero. Operating under LOS C and above condition shows that high percentage vehicles are now traveling in platoons, and PTSF is quite noticeable.

The study has also analyzed LOS with passing lane by using HCS 2010 software to evaluate the improvement on the performance of two-lane, two-way road. The result obtained from HCS 2010 has shown in the table 11.

Table 11: Summery of LOS result obtained from HCS 2010 with and without passing lane

Summary of Result From HCS 2010							
5Km Segment between	**Condition**	**FFS (mil/h)**	**ATS (mil/h)**	**PTSF (%)**	**TT15 (h)**	**LOS**	**Difference with and without passing lane TT15 (h)**
Sululta-Chancho	Without passing lane	49	35.9	74.7	17	E	0.9
	With passing lane	49	38	53.8	16.1	E	
Chancho-Sululta	Without passing lane	50	36	73.6	16.2	E	0.5
	With passing lane	50	37.9	56	15.7	E	
Addisababa-Sendafa	Without passing lane	51	43.3	42.7	5.4	D	0.2
	with passing lane	51	45.5	30.1	4.2	C	
Sendafa-Addisababa	Without passing lane	52	45.2	44.4	5.5	C	0.2
	With passing lane	52	47.6	31.4	5.3	C	
Sebeta-Tulubulo	Without passing lane	51	43.3	49.7	6.7	D	0.4
	With passing lane	51	45.5	34.3	6.3	C	
Tulubulo-Sebeta	Without passing lane	53	45.1	52.3	6.9	C	0.3
	With passing lane	53	47.5	36.5	6.6	C	

As the result shown in the above table 11, LOS has been determined for the calculated ATS and PTSF values of 5km length of Sululta-Chancho road segment without passing lane. Although PTSF value of this road segment has been fallen within the LOS D category, ATS value has been fallen within the LOS E category; thus, ATS value has governed the level of service under this roadway and traffic conditions operated at LOS “E”. Similarly, for the same flow condition and free flow speed, this road segment with passing lane has been operated at LOS “E”. In this case, although PTSF value has been fallen within the LOS C category, ATS has been fallen within the LOS E category; thus, ATS has governed the level of service for this two-lane highway under these roadway and traffic conditions. Since, as the ATS value governs, this road segment has operated at LOS E. Hence, provision of passing lane is not significant important to improve LOS for this road segment. However, the result shows that total vehicle peak 15 min travel time changes significantly from 17 hour to 16.5 hour due to passing lane provision. Thus, provision of passing lane is important to reduce travel time in two –lane, two-way roads. Furthermore, calculated Volume capacity ratio, v/c is 0.48, which shows the roadway segment is not reached to the capacity flow limit while the road segment operate with undesirable LOS.

Similarly, the LOS result has been determined for the calculated ATS and PTSF values of 5km length of Chancho- Sululta road segment without passing lane. Although PTSF has been fallen within the LOS D category, ATS has been fallen within the LOS E category; thus, ATS has been governed and operated at LOS “E” for this two-lane highway for current operating condition. For similar flow and free flow speed, this segment with passing lane has operated at LOS “E”. In this respect, although PTSF value has been fallen within the LOS C category, ATS has been fallen within the LOS E category; thus, ATS has governed the level of service for this two-lane highway under these roadway and traffic conditions. Since, as ATS value governs, this road segment has operated at LOS E. Hence, provision of passing lane is not significant important to improve LOS for this road segment. Nonetheless, total vehicle peak 15 min travel time changes significantly from 16.2 hour to 15.7 hour. In this case, travel time saving is being exhibited due to provision of passing lane. Therefore, provision of passing lane for this road segment has advantage in terms of travel time saving.

Addis Ababa-Sendafa and Sebeta-Tulubulo 5 km road segment without passing lane currently operate at LOS “D”. Although PTSF falls within the LOS B category, ATS falls within the LOS D category; thus, ATS governs the level of service for this two-lane highway under these roadway and traffic conditions. However, for similar flow and free flow speed condition, with 0.8 mile length of passing lane both LOS and travel time changed from “D” to “C” and from 16.2 hour to 15.7 hour for Addis Ababa-Sendafa road segment and from 6.7 to 6.3 for Sebeta –Tulubulo road segment respectively. Although LOS improvement has been exhibited due to provision of passing lane for these roads segment, the level of improvement has not been to the desired level.

Among selected road segment for this study currently, chancho-Sululta and Sululta-Chancho operate with severely with undesirable LOS compared to the remaining segment. By providing the passing lane, highest travel time saving is obtained from chancho-Sululta and Sululta-Chancho road segment due to high traffic flow compared to other road segment.

To summarize, though provision of passing lane has been brought a significant changes for the value of PTSF, small value of ATS increment has been exhibited for current analysis condition. Hence, provision of passing lane has not improved LOS from one letter scheme to the next better letter scheme for those roads segment, which ATS value governs for LOS determination unless otherwise calculated value of ATS without passing lane is approaching to the highest marginal value that set out in HCM. Generally, provision of passing lane has not advantageous for LOS improvement from the worst LOS letter scheme to the next better LOS letter scheme for these selected road segments for this study to the desired level. On the other hand, provision of passing lane has significant importance in terms of travel time saving.

From the analysis result , Volume to capacity ratio shows that even the traffic flow is very small compared to capacity, the roads segment operate at undesirable performance. Even, the road has high capacity the selected road segments have operated under poor performance due to presence of high proportion of heavy truck, volume of traffic in the opposite lane, etc. Thus, performance analysis is needed to closely follow up of the road and to enhance the performance via providing different performance improvement mechanism. Hence, road Agency, intervention is required to improve LOS to the desired level and to meet the intended purpose (i.e. mobility) of those roads segment.

4.2. Result and Discussion of LOS for Future Five Years

The study has assessed and predicted LOS for the forecasted traffic flow condition, including travel time saving for selected roads segment for this study with and without passing lane. The prediction of LOS for the future Five-year analysis period has been performed using HCS 2010 software. The purpose of this analysis is to predict the quality of service for the future condition either those roads segment operate more severely than current condition or not.

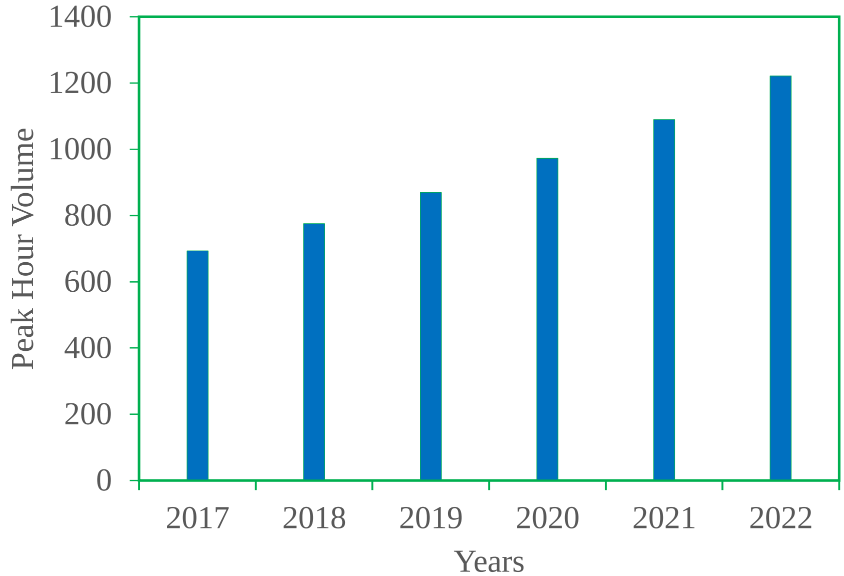

Fig 9: Projected peak traffic volume for Sululta-Chancho road Segment

Fig 9 shows the forecasted peak hour traffic flow based on traffic flow trends that have been previously shown in the ERA traffic count record.

The HCS 2010 software simulation result has showed that for the entire roads segment selected for this study except Sululta-Chancho and Chancho-Sululta direction, which operate at LOS E for the current condition, will be operated at LOS D after one year. Sululta-chancho segment will approaches to the capacity after five years. From simulation result, it is also observed that for Addis Ababa-Sendafa, Sendafa –Addis Ababa, Sebebta –Tulubulo and Tulubulo-Sebeta roads segment will continued operating with LOS D similar to current condition for 5 years before changed to the next worst LOS letter scheme. By providing passing lane, Addis Ababa-Sendafa, Sendafa –Addis Ababa and Tulubulo-Sebeta road segment will operate with LOS C. However, LOS improvement is not to desired level. Remaining roads segment will operated with same LOS for both with and without passing lane.

From HCS 2010 simulation, it is also noted that when the peak hour demand volume of the road increase then peak 15 min travel time difference for two-lane, two-way road segment with and without passing lane increase. All the simulation result for LOS and peak 15-travel time difference for the analysis period shown in the following tables and graphs.

Table 12: Five-Year Analysis Result for Addis Ababa-Sendafa Road Segment

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With-out PL	With PL	With -out PL	With PL	With-out PL	With PL		Without PL	With -out PL
Addis Ababa-Sendaf	2018	285	44.9	31.2	45.0	47.0	5.6	5.3	0.3	D	C
	2019	302	47.0	32.3	44.6	46.9	6.0	5.7	0.3	D	C
	2020	320	49.2	33.9	44.3	46.6	6.4	6.1	0.3	D	C
	2021	340	50.9	35.5	44.0	46.3	6.8	6.5	0.3	D	C
	2022	360	51.1	35.7	43.8	46.1	7.2	6.9	0.3	D	C

The result shown in the above table 12, for the future 5 years with and without passing scenario, the Addis Ababa –Sendafa road segment will operate at LOS D with increasing of peak traffic flow from 285 to 360. Within this 5 years analysis period, major change is not observed from current LOS condition. By providing passing lane, this segment will operates at LOS C in this analysis period while without passing lane it will operates at LOS D. In this analysis period constant travel time difference with and without passing lane (i.e.0.3h) is observed.

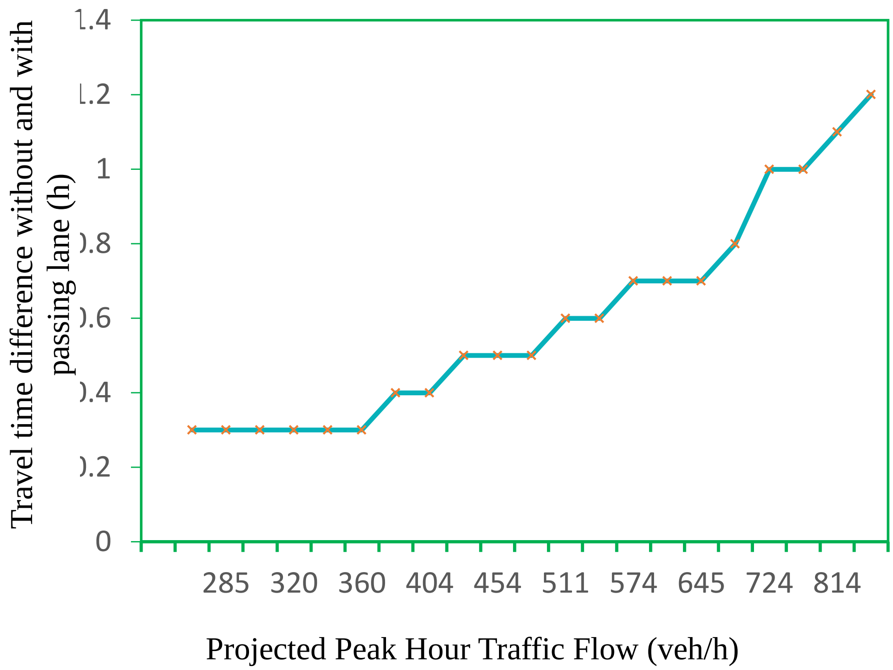

Fig 10: Travel time difference with and without PL versus peak traffic flow (Addis Ababa –Sendafa)

The HCS 2010 software result has presented in the above fig 10 and noted that when the peak hour traffic flow increase the total vehicle travel time difference with and without passing lane also increase.

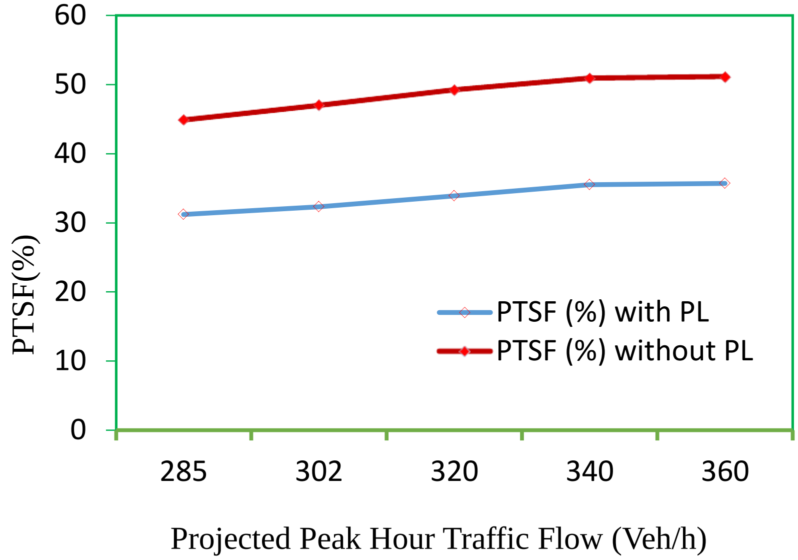

Fig 11: Peak-hour traffic flow versus PTSF with and without PL (Addis Ababa-Sendafa)

From the result shown in the above fig 11, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 11 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 14.9% of percent time spent following decrement in Addis Ababa-Sendafa road segment has been exhibited due to passing lane provision.

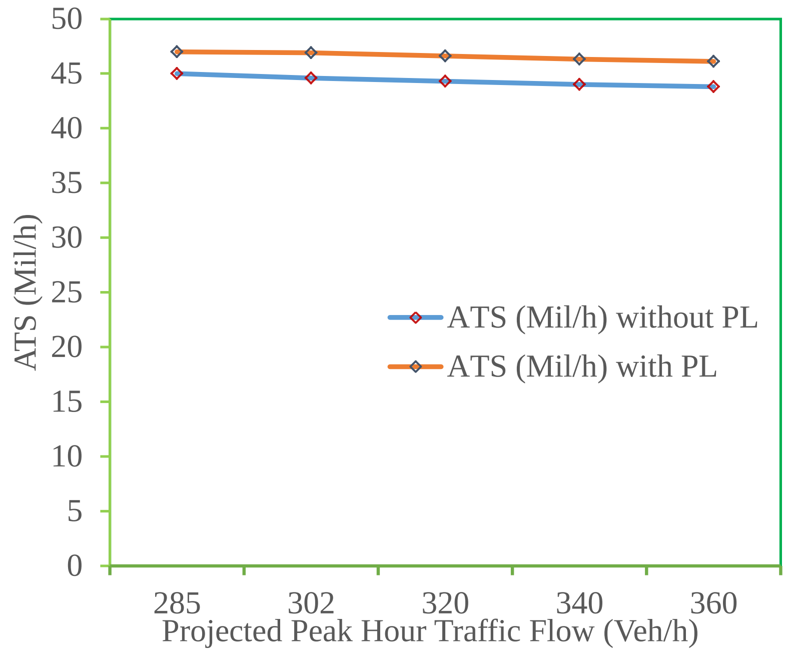

Fig 12: Peak-hour traffic flow versus ATS with and without PL (Addis Ababa -Sendafa)

Fig 12 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also slightly increase. For projected peak traffic flow from 2017 up to 2022, on average 2.24 mil/h average travel speed increment in Addis Ababa-Sendafa road segment due to passing lane. Thus, increment of ATS due to passing lane is minimal compared to decrement of PTSF value.

Table 13: Sendafa –Addis Ababa LOS analysis result for projected year

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With -out PL	With PL	With -out PL	With PL	With -out PL	With PL		With-out PL	With-out PL
Sendafa -Addis Ababa	2018	295	46.8	32.1	44.8	47.1	5.8	5.5	0.3	D	C
	2019	313	47.4	32.6	44.7	47.0	6.2	5.9	0.3	D	C
	2020	332	49.5	34.2	44.3	46.6	6.6	6.3	0.3	D	C
	2021	352	51.6	36.0	44.0	46.3	7.0	6.7	0.3	D	C
	2022	373	54.8	38.3	43.7	46.0	7.5	7.1	0.4	D	C

The researcher has presented the HCS 2010 software result for the analysis of LOS for the five years analysis period with and without passing lane scenario. For the five-year analysis period, Sendafa -Addis Ababa road segment operate at LOS D without any intervention. By providing passing lane, this road segment operates at LOS C. Constant total vehicle travel time difference with and without passing lane has been observed for the five-year analysis period.

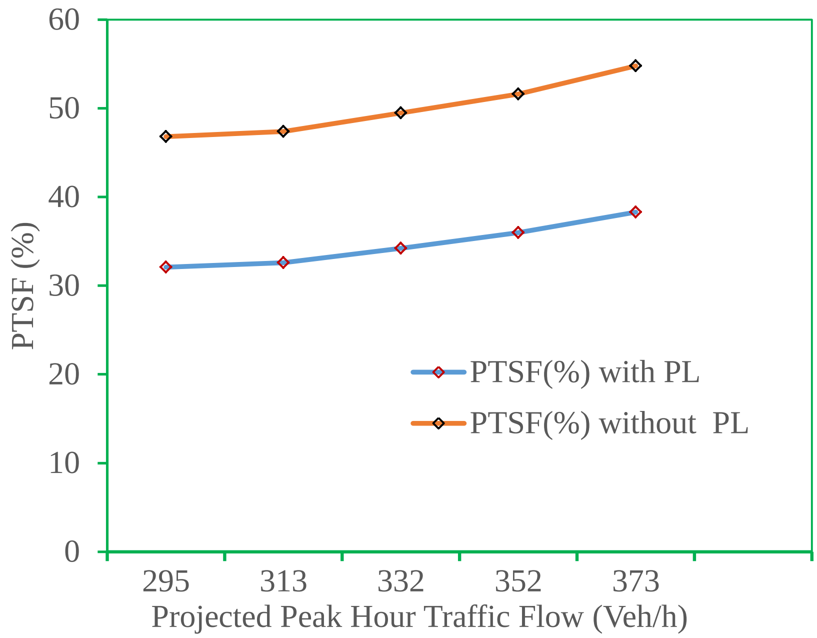

Fig 13: Peak-hour flow versus PTSF with and without PL (Sendafa-Addis Ababa)

From the above fig 13, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 13 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 15.38% of percent time spent following decrement in Sendafa- Addis - Ababa road segment is observed due to passing lane.

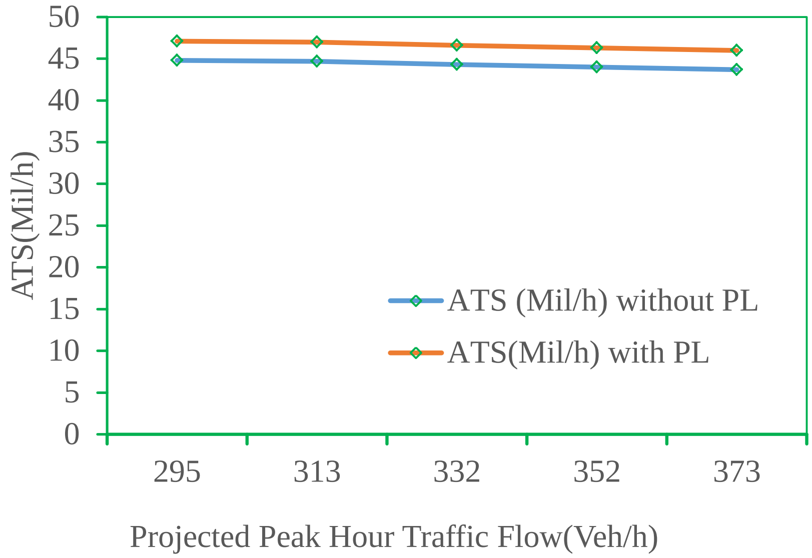

Fig 14: Peak hour flow versus ATS with and without PL (Sendafa- Addis Ababa)

Fig 14 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also slightly increase. For projected peak traffic flow from 2017 up to 2022, on average 2.3 mil/h average travel speed increment in Sendafa-Addis Ababa road segment is observed due to passing lane.

Table 14: Sululta-Chancho LOS analysis result for projected year

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With -out PL	With PL	With -out PL	With PL	With -out PL	with PL		With-out PL	With -out PL
Suluta – Chancho	2018	776	78.4	56.9	34.5	36.5	19.8	18.7	1.1	E	E
	2019	869	82.2	60.4	33.5	35.5	22.8	21.6	1.2	E	E
	2020	973	85.4	62.9	31.8	33.6	26.9	25.5	1.4	E	E
	2021	1090	88.7	65.3	29.9	31.6	32.1	30.4	1.7	E	E
	2022	1221	90.9	66.9	28.7	30.4	37.4	35.4	2.0	E	E

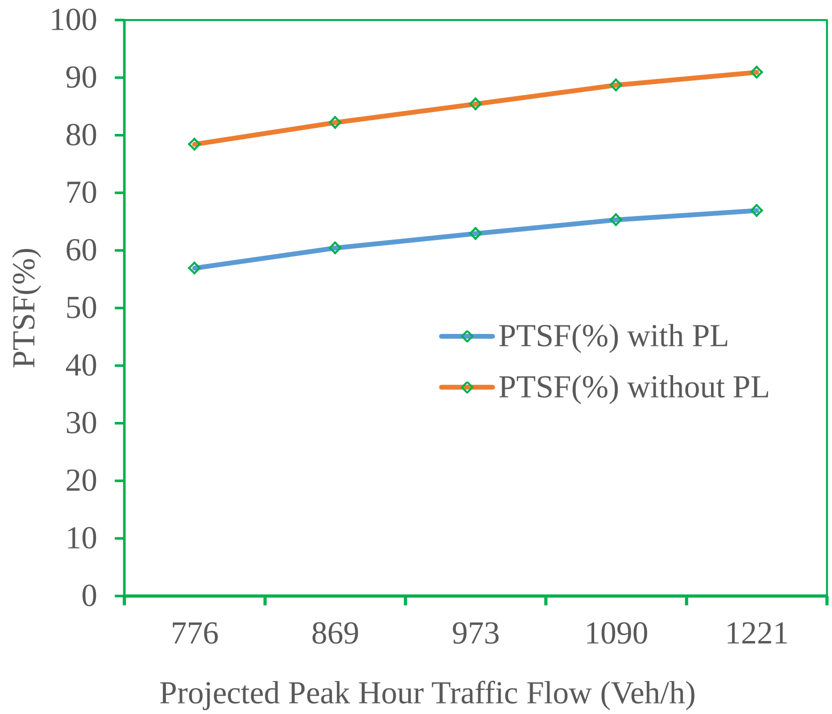

Fig 15: Peak-hour flow versus PTSF with and without Pl (Sululta –Chancho)

From the above fig 15, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 15 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 22.64% of percent time spent following decrement in Sululta-Chancho road segment is observed due to passing lane.

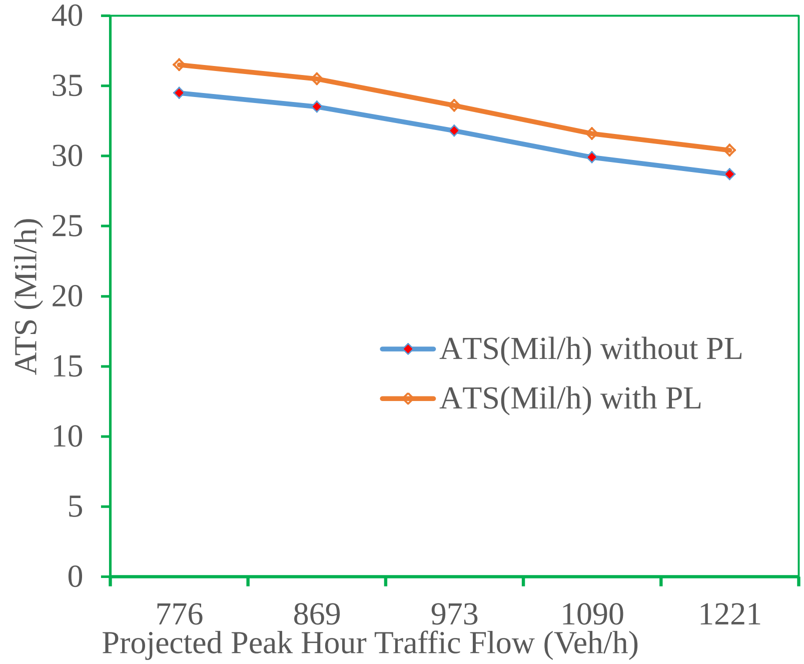

Fig 16: Peak-hour flow versus ATS with and without Pl (Sululta –Chancho)

Fig 16 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also slightly increase. For projected peak traffic flow from 2017 up to 2022, on average 1.84 mil/h average travel speed increment in Sululta-Chancho road segment is observed due to passing lane.

Table 15: Chancho-Sululta LOS analysis result for projected year

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With -out PL	With PL	With-out PL	With PL	With-out PL	with PL		with out PL	with PL
Chancho – Sululta with growth rate 11%	2018	751	77.7	56.3	35.8	37.8	18.5	17.5	1.0	E	E
	2019	834	81.3	59.5	34.5	36.5	21.3	20.1	1.2	E	E
	2020	926	84.2	62.0	33.7	35.6	24.2	22.9	1.3	E	E
	2021	1027	87.7	64.6	30.9	32.6	29.3	27.7	1.6	E	E
	2022	1140	90.1	66.4	28.7	30.4	34.9	33.1	1.8	E	E

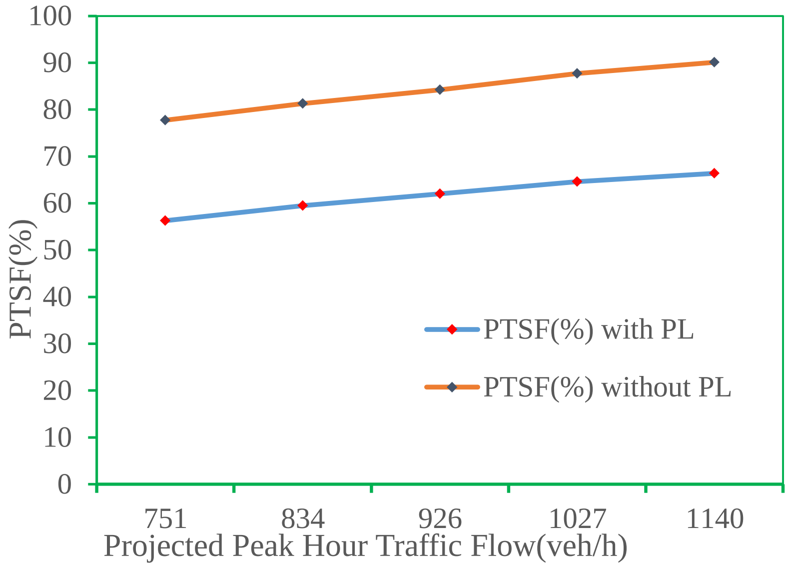

Fig 17: Peak-hour flow versus PTSF with and without PL (Chancho–Sululta)

From the above fig 17, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 17 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 22.44% of percent time spent following decrement in Chancho-Sululta road segment due to passing lane.

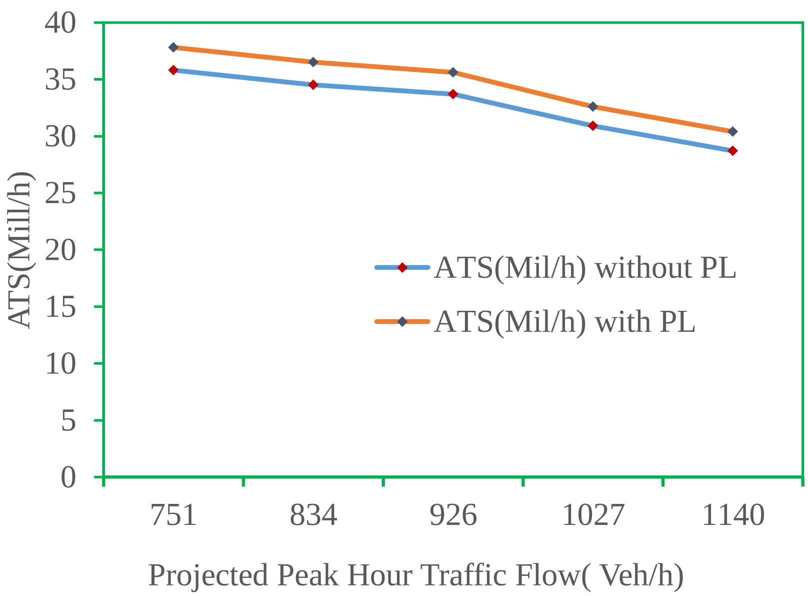

Fig 18: Peak-hour flow versus ATS with and without PL (Chancho–Sululta)

Fig 18 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also slightly increase. For projected peak traffic flow from 2017 up to 2022, on average 1.86 mil/h average travel speed increment in Chancho-Sululta road segment due to passing lane.

Table 16: Sebeta –Tulubulo LOS analysis result for projected year

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With-out PL	With PL	With -out PL	With PL	With-out PL	with PL		with out PL	With -out PL
Sebeta – Tulubulo	2018	348	52.2	36.5	42.9	45.1	7.1	6.8	0.3	D	C
	2019	369	52.1	36.4	42.5	44.7	7.6	7.3	0.3	D	D
	2020	391	54.4	38.0	42.2	44.4	8.1	7.7	0.4	D	D
	2021	415	56.7	39.7	41.7	43.9	8.7	8.3	0.4	D	D
	2022	439	58.4	40.9	41.5	43.6	9.3	8.9	0.4	D	D

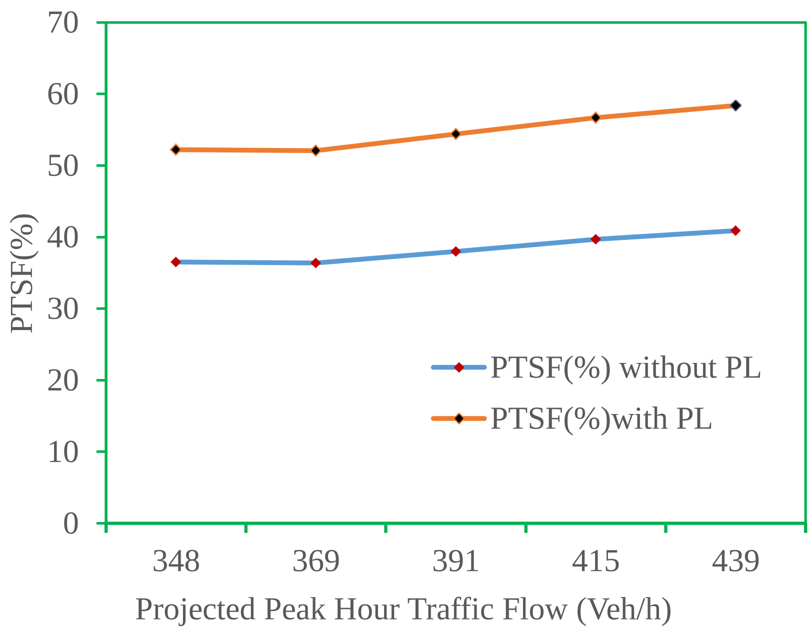

Fig 19: Peak hour flow versus PTSF with and without PL (Sebeta-Tulubulo)

From the above fig 19, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 19 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 16.46% of percent time spent following decrement in Sebeta-Tulubulo road segment due to passing lane.

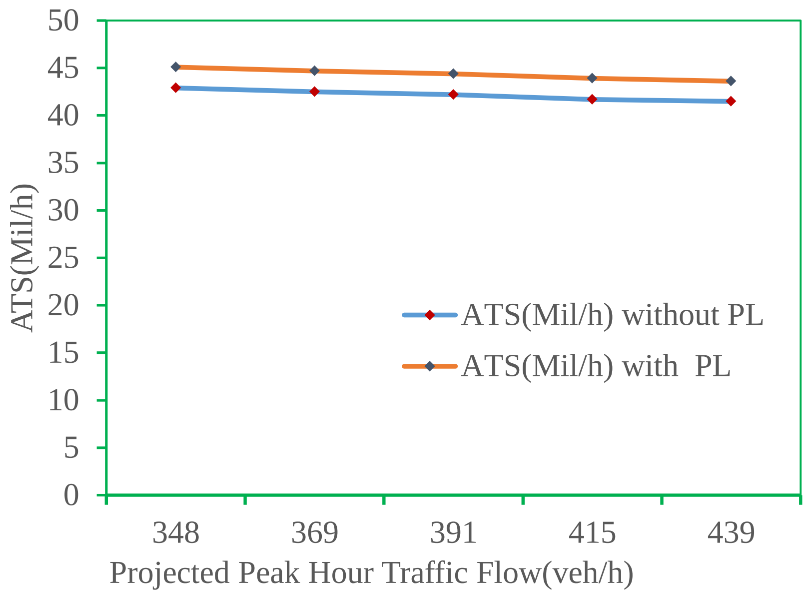

Fig 20: Peak hour flow versus ATS with and without PL (Sebeta-Tulubulo)

Fig 20 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also slightly increase. For projected peak traffic flow from 2017 up to 2022, on average 2.18 mil/h average travel speed increment in Sebeta-Tulubulo road segment due to passing lane.

Table 17: Tulubulo -Sebeta LOS analysis result for projected year

Segment	Year	Directi-onal peak flow (veh/h)	PTSF (%)		ATS (Mil/h)		TT15 (h)		Difference with and without PL TT15 (h)	LOS	
			With -out PL	With PL	With-out PL	With PL	With-out PL	with PL		with out PL	With-out PL
Tulubulo – Sebeta with growth rate of 7%	2018	379	53.4	38.8	44.6	47	7.5	7.3	0.2	D	C
	2019	405	55.3	38.7	44.4	46.8	8.0	7.6	0.4	D	C
	2020	434	57.1	40.0	44.0	46.3	8.7	8.3	0.4	D	C
	2021	464	60.3	42.3	43.7	46.0	9.4	8.9	0.5	D	C
	2022	497	62.2	43.7	43.2	45.5	10.1	9.6	0.5	D	C

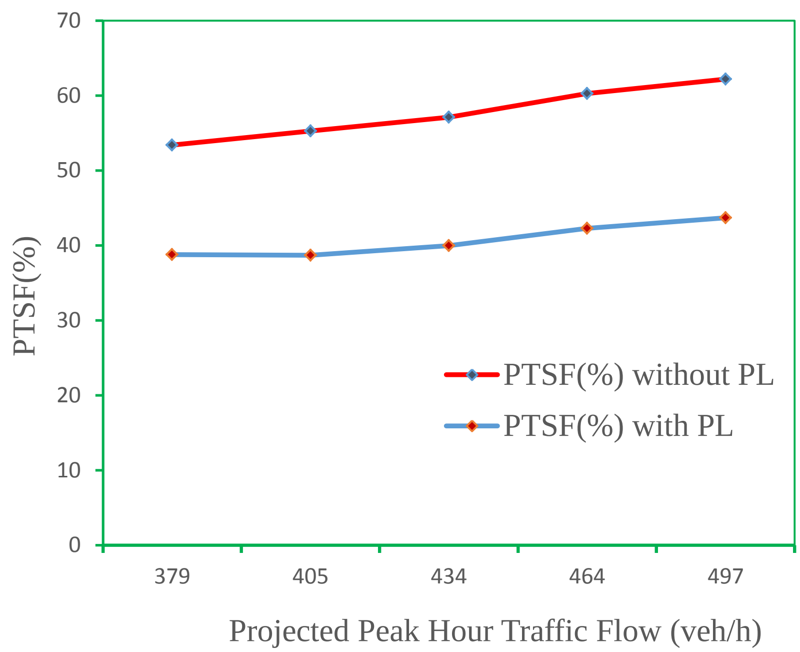

Fig 21: Peak- hour flow versus PTSF with and without PL (Tulubulo-Sebeta)

From the above fig 21, it is noted that when peak-hour traffic flow increase the percent time spent following also increase. Fig 21 also shows that the segment with passing lane percent time spent following vehicle significantly decrease. For projected peak traffic flow from 2017 up to 2022, on average 16.96% of percent time spent following decrement in Tulubulo-Sebeta road segment due to passing lane.

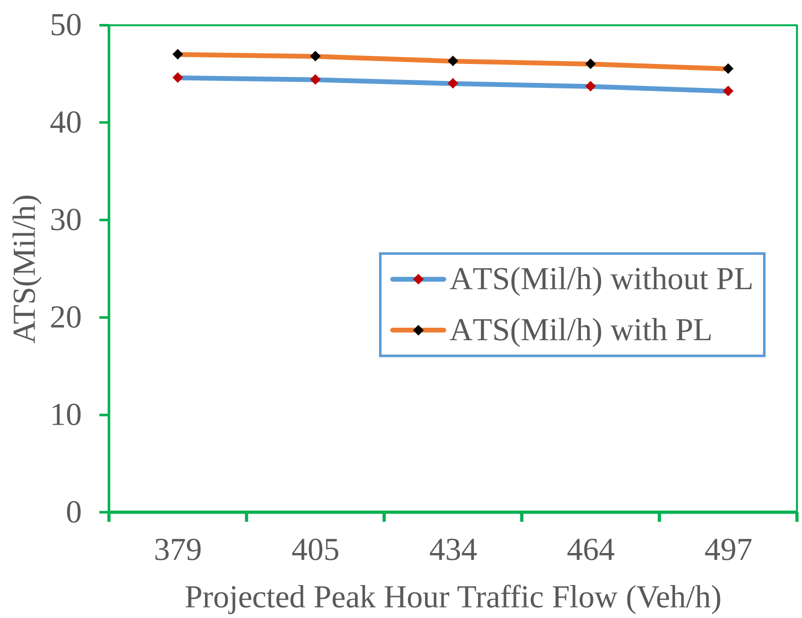

Fig 22: Peak hour flow versus PTSF with and without PL (Tulubulo-Sebeta)

Fig 22 shows when peak-hour traffic flow increase, Average Travel speed also decrease. With passing lane average travel speed also significantly increase. For projected peak traffic flow from 2017 up to 2022, on average 2.34 mil/h average travel speed increment in Tulubulo – Sebeta road segment due to passing lane.

To summarize, from future five-year analysis result, it is noted that the 5km length of Addis Ababa-Sendafa road segment, the PTSF value has been fallen within the LOS B category while ATS has been fallen within the LOS D category; thus, ATS governs the level of service. Hence, this road segment for the predicted traffic flow conditions will then operate at LOS "D". Predicted result, also shows similar LOS result exhibited for current and future five years.

For the calculated ATS and PTSF values of 5km length of Sendafa-Addis Ababa road segment for future five year, PTSF falls within the LOS B category and ATS falls within the LOS D category; thus, ATS governs the level of service for this two-lane highway under these roadway and traffic conditions will then operate at LOS "D".

For the calculated ATS and PTSF values of 5km length of : Sululta-Chancho road segment for future five year, both PTSF and ATS falls within the LOS E category; thus, for this two-lane highway under these roadway and traffic conditions will operate at LOS "E".

For the calculated ATS and PTSF values of 5km length of : Chancho-Sululta road segment for future five year, both PTSF and ATS falls within the LOS E category; thus, for this two-lane highway under these roadway and traffic conditions will operate at LOS "E".

For the calculated ATS and PTSF values of 5km length of Sebeta –Tulubulo road segment for future five year, PTSF falls within the LOS C category and ATS falls within the LOS D category; thus, ATS governs the level of service for this two-lane highway under these roadway and traffic conditions operate at LOS "D".

For the calculated ATS and PTSF values of 5km length of Tulubulo – Sebetaroad segment for future five year, PTSF falls within the LOS C category and ATS falls within the LOS D category; thus, ATS governs the level of service for this two-lane highway under these roadway and traffic conditions will operate at LOS “D”.

From the analysis result, it is also noted that except Sululta-Chancho and Chancho-Sululta road segment the remaining road segment as per PTSF value the LOS has been fallen within acceptable level (i.e. LOS B). However, ATS values govern the LOS determination and all the road segment has been fallen to the undesirable LOS. Since, the ATS value govern, it is possible to improve the LOS by providing the different road elements that maximizing the value of ATS such as sufficient lane and shoulder width, reducing access point density etc. Therefore, to improve the LOS to the desired level except Sululta-Chancho and Chancho – Sululta road segments, the intervention of road agency shall be focus only on the parameter that maximize the value of ATS. For Sululta-Chancho and Chancho –Sululta road segments, the LOS improvement provision shall be focus on the increasing the value of ATS and decreasing the value of PTSF.

4.3. Simulation of peak 15 min travel time difference with and without passing lane with Free Flow Speed.

The objective of the simulation of peak 15 min travel time difference with and without passing lane for different value of free flow speed using HCS 2010 software is to show the trend how the travel time difference is being affected free flow estimation uncertainty due to different factor. Lane width, shoulder width and access point density are some of the factor affecting the free flow speed. The simulation has been done in HCS 2010 software for various value of FFS by keeping all other input parameter in the software is constant.

The result of simulation shows that the peak 15 min travel time difference with and without passing lane for different value of free flow speed is constant. The result plotted as shown the following figure

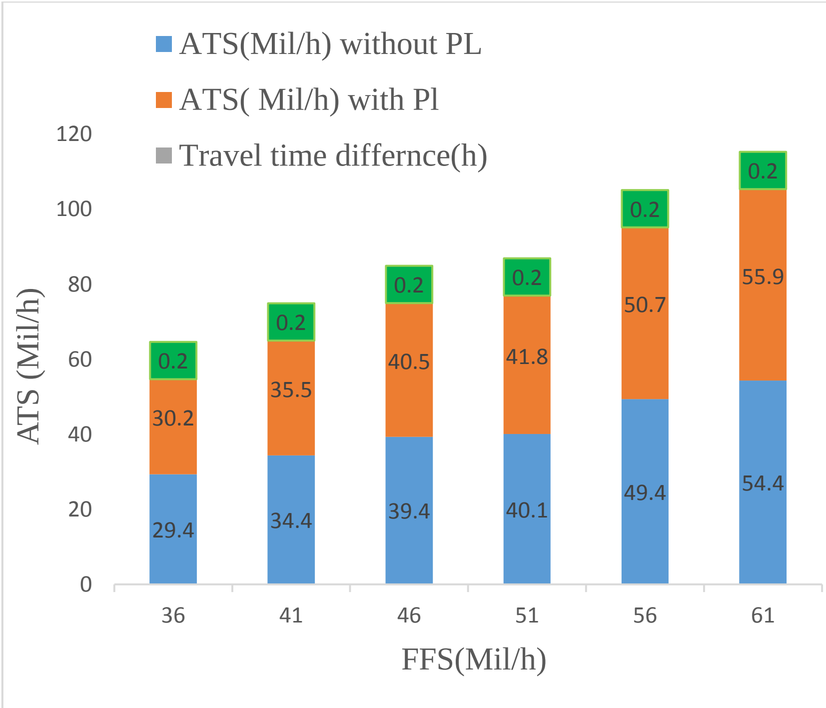

Fig 23: Peak 15-Min travel time difference versus FFS

From this figure, it is noted that the peak 15 min travel time difference with and without passing lane is constant for different value of free flow speed. Peak 15 min travel time difference for with and without passing lane used to economic analysis of passing lane. Peak 15 min travel time difference is benefit, which will obtained from proposed improvement of LOS (i.e. passing lane). Hence, due to free flow speed uncertainty in the estimation travel time saving with and without passing lane is not affected.

4.4. Proposed LOS Improvement

From the analysis result, it is noted that the entire roads segment selected for this study currently and for the future five years operate with undesirable LOS. Even if, this study has been carried out on the flat terrain in which better LOS is anticipated, all the roads segment operate with undesirable LOS. Hence, to improve the LOS of these roads segment, the roads agency intervention is required. From result shown in section 4.1 and 4.2 except Sululta-Chancho and Chancho-Sululta road segment, the remaining road segment ATS values govern the LOS determination and all the road segment falls to the undesirable LOS. ATS reflects mobility on a two-lane highway. Since, ATS governs LOS, mobility of those roads segment greatly affect. As result, the intended purpose of those roads (i.e. mobility) adversely affected. Hence, the road agencies intervention is required to improve the operational performance by providing and implementing different geometric parameters of those roads through focusing on enhancing ATS value.

Ethiopia is located in the horn of Africa in the Easter part. However, Ethiopia is not a member of Eats Africa Community. East Africa Community (EAC) was established for increasing economic, political, social, and cultural integration among the region member's countries (Irving, et al, 2012). LOS practice in the region is advanced in such a way that the country members have guidelines for selection of design levels of service for the different classes of rural roads and there are design manuals for EAC Partner States in which all those parameters are given (Uwitonze, 2014). In the region, once a level of service has been identified as applicable for design, the accompanying service flow rate logically become the design service flow rate, implying that if the traffic flow rate using the facility exceeds that value, operating conditions will fall below the level of service for which the facility was designed. Once a level of service has been selected, it is desirable that all elements of the roadway are consistently designed to this level. The choice of parameter used in the design manual were guided by AASHTO as guidelines for a tool in which they provide the selection of design levels of services for specified combinations of road functional class and terrain type. EAC guidelines has been recommending adopting of minimum of LOS B for the level terrain roads, LOS C for mountainous terrain roads in the selection of design levels of service for the mobility functional classes of the road.

East Africa Community also builds one stop border post to facility trade and transport in the region. Even though, Ethiopian is not member of EAC, to facilitate the trade and transport between Ethiopia and Kenya construction of one stop border post at Moyale border is ongoing, which might indicate that Ethiopia will going to join in EAC. Hence, the researcher suggest that adopting minimum LOS like EAC guideline in Ethiopia as minimum LOS as B for level terrain and LOS as C for mountainous terrain of mobility class of the road as base line to design the road by considering the appropriate design parameter like sufficient lane width, shoulder width and limit number of access point etc. In the next section of this study, it has been discussed the impact of lane and shoulder width and other factor to obtain the minimum recommended LOS in EAC manual and to conclude and suggest for concerned body the intervention requirement to improve LOS up to this desired level.

4.4.1. Effect of Lane and Shoulder Width and Others Parameter on LOS Improvement

Design element such as lane and shoulder width, horizontal radius, super –elevation, sight distance and gradient are directly related to design speed (ERA Manual, 2013). Narrow lane widths cause drivers to drives lower on local streets (Fitzpatrick et al, 2003). In highway capacity manual, LOS is defined as a qualitative measure describing operational conditions within a traffic stream, based on service measure such as speed and travel time, freedom to maneuver, traffic interruption, comfort, and convenience. Among these service measures, the operating speed has also significant effect to increase the level of the service of the roads. The operating speed of the vehicle in the traffic stream also depends on lane and shoulder width (HCM, 2010).

Level of Service is mainly depends on the value of free flow speed and traffic flow. If high value of free flow speed maintained, then the road will serves within desired level of service. Determination of Free flow speed is also depends on base free flow speed. To improve the LOS to the desired level from the beginning, it necessary to find the parameter that increase the value of base free flow speed. Once, the parameters that influence to increase the values of BFFS up to desired level to improve the LOS are identified, then the next step will be a matter of decision to provide and implement these parameters to increase LOS within desired level based on functional classification of the roads. The AASHTO 1990 Green Book explains that roadway networks provide dual roles in that they provide both access to property and travel mobility. Regulated access control is needed on arterials to ensure their primary function of mobility. On the other hand, the function of local roads and streets is to provide access, which inherently limits mobility. The relationship between mobility and access is one of give and take, with collectors and arterials serving both purpose.

The Center of international importance and roads terminating at international boundaries are linked with Addis Ababa by truck roads, which the anticipated AADT is greater than 10000 and design standard ranges from DC4 to DC8 (ERA,2013). The main function of those truck roads are providing of mobility for peoples and goods and the anticipated operating speed is relatively high. Hence, to maintain this anticipated operating speed every parameter that enhances the operating speed such as standard lane and shoulder width, controlled access point density etc., shall be provide and implemented.

According to ERA 2013 manual, there is insufficient quantifiable evidence to justify carriageway and shoulder widths purely on economic grounds using whole life cost principle. This requires knowledge about the cost of accident and their causes, knowledge about the road deterioration and the effect of maintenance. Because of this, the road width set in the manual is based on the long-term international evolution of such standards modified by local consideration. Judgment rather than prices calculations are required and the standard is based on consensus. From DC4 to DC8 standard the lane width of the roads ranges from 3m to 3.65m.The width of carriageway has a great influence on the road safety and wider roads requires less shoulder maintenance because fewer vehicles drive over the vulnerable edge between the running surface and shoulder. An initial step in the design process is defining the function that a facility is to serve. The ability of the roadway to provide that function is related to the anticipated volume of traffic, the anticipated operating speed, and the geometric criteria present. In general, good geometric design means providing the appropriate level of mobility and land use access for motorists, bicyclists, and pedestrians while maintaining a high degree of safety.

Free Flow Speed on two-lane highways covers a significant range, from as low as 45 mil/h to as high as 70 mil/h. To estimate the FFS, the analyst must characterize the operating conditions of the facility in terms of a BFFS that reflects the nature of the traffic and the alignment of the facility. Unfortunately, because of the broad range of speeds that occur and the importance of local and regional factors that influence driver-desired speeds, little guidance on estimating the BFFS shall be given. Estimates of BFFS can be developed based on speed data and local knowledge of operating conditions on facilities. As will be seen, once the BFFS is determined, adjustments for lane and shoulder widths and for the density of un-signalized access points are applied to estimate the FFS. In concept, the BFFS is the speed that would be expected based on the facility's horizontal and vertical alignment, if standard lane and shoulder widths were present and there were no roadside access points. Thus, the design speed of the facility might be an acceptable estimator of BFFS, since it is based primarily on horizontal and vertical alignment. Posted speed limits may not reflect current conditions or driver desires speed (HCM, 2010).

While adjustments to a base free-flow speed (BFFS) are provided as part of the methodology, no firm guidance on determining the BFFS is given (HCM, 2010). Specific guidance on choosing a value for BFFS is not offered, due to the wide range of speed conditions on two-lane highways and the influence of local and regional factors on driver-desired speeds. Speed data and local knowledge of operating conditions on similar facilities can be used in developing an estimate of BFFS (HCM, 2010).

Hence, local knowledge in the determination of BFFS might indicate that the road agency can decide and/or estimate the appropriate value of BFFS, which enhance the LOS to the desired level by providing the better standard road related to anticipated LOS.

The speed data was collected from all roads segment selected for this study using Radar-Gun and 85th percentile is plotted as follows. The purpose of 85th percentile speed determination is to compare the value obtained with Ethiopian speed limit.

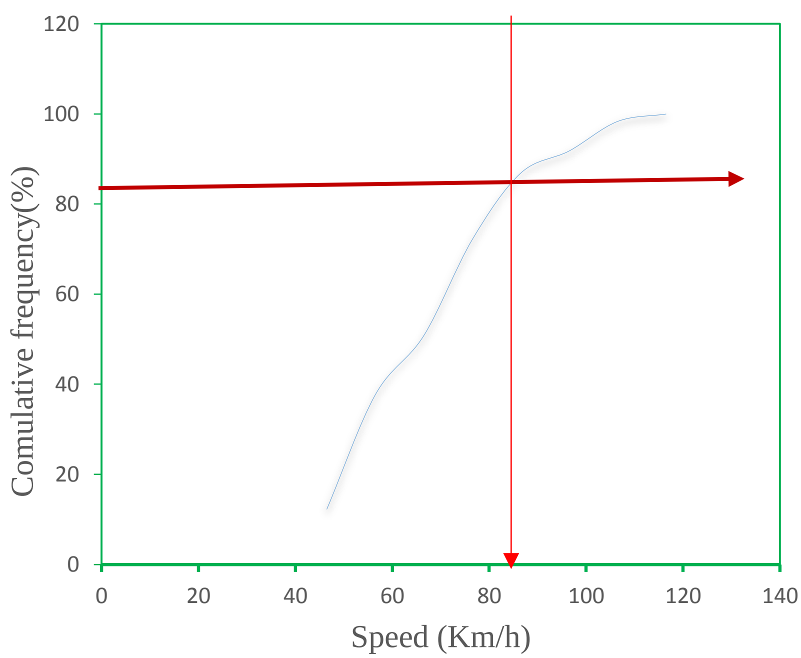

Fig 24: 85th percentile speed for Sululta-Chancho road segment

- 85th percentile speed of Sululta chancho is 85km/h
- Average speed of Sululta chancho is 76.78km/h

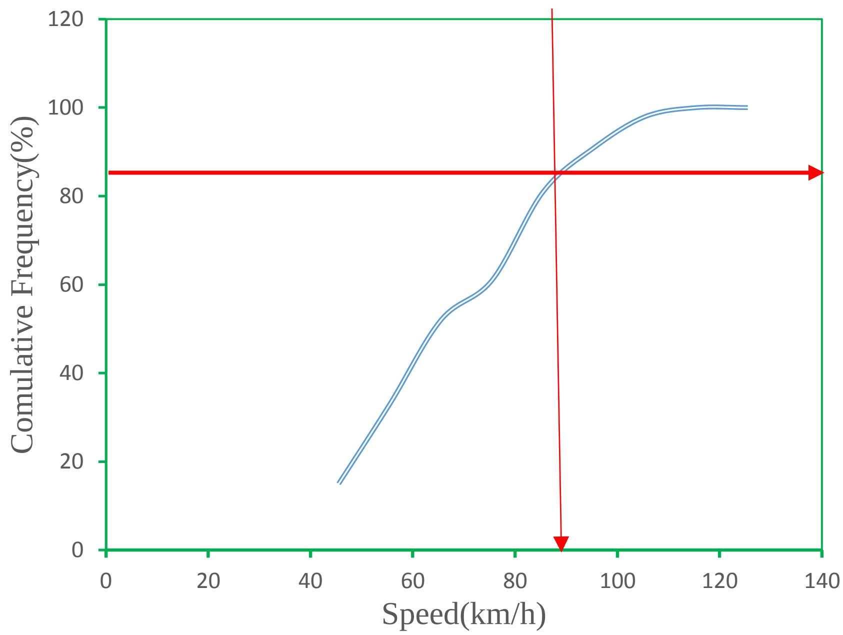

Fig 25: 85th percentile speed of Chancho-Sululta road segment

- 85th percentile speed of chancho- Sululta is 88km/h
- Average speed of chancho- Sululta is 77.92km/h

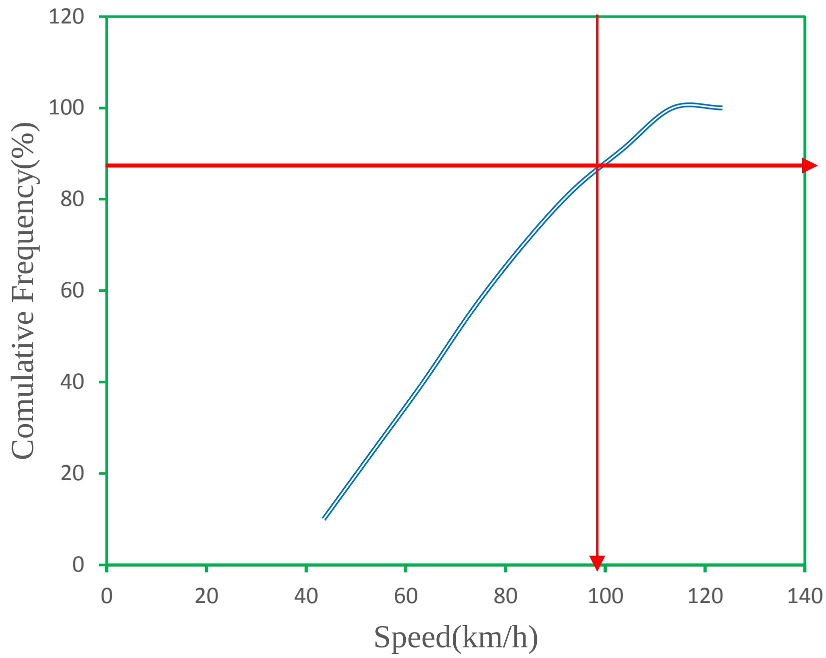

Fig 26: 85th percentile speed of Addis Ababa-Sendafa road segment

- 85th percentile speed of Addis Ababa-Sendafa is 98km/h
- Average speed of Addis Ababa-Sendafa is 81.26 km/h

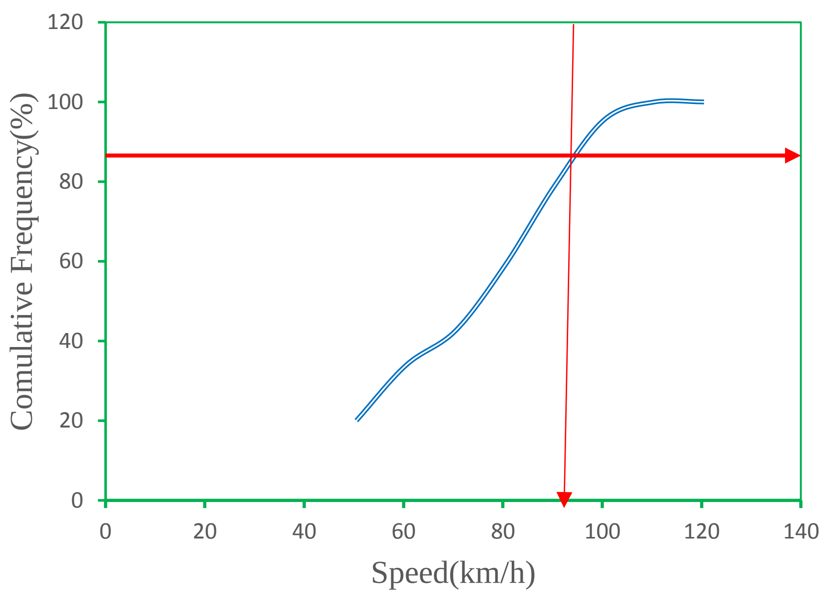

Fig 27: 85th percentile speed of Sendafa-Addis Ababa road segment

- 85th percentile speed of Sendafa-Addis Ababa is 95km/h

- Average speed of Sendafa-Addis Ababa is 81.6 km/h

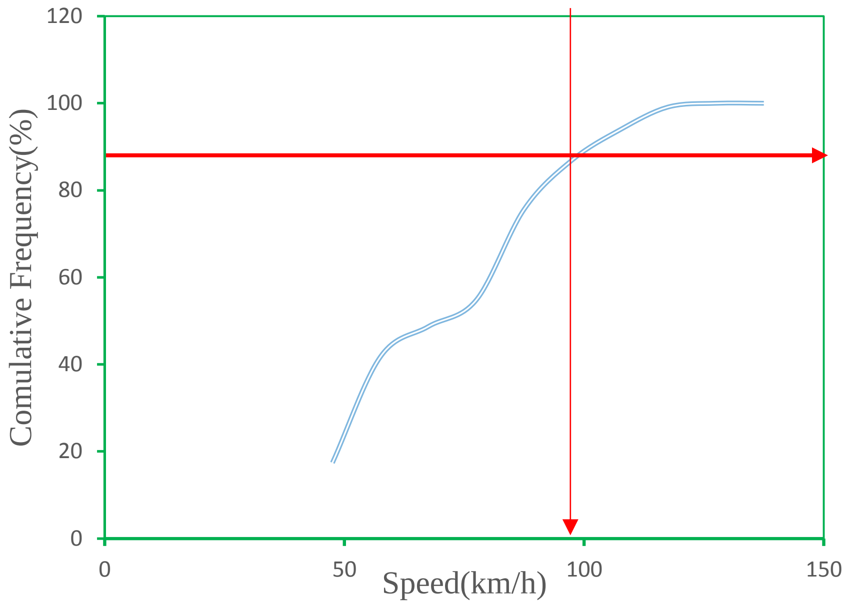

Fig 28: 85th percentile speed of Sebeta Tulubulo road Segment

- 85th percentile speed of Sebeta Tulubulo is 96km/h
- Average speed of Sebeta Tulubulo is 79.97 km/h

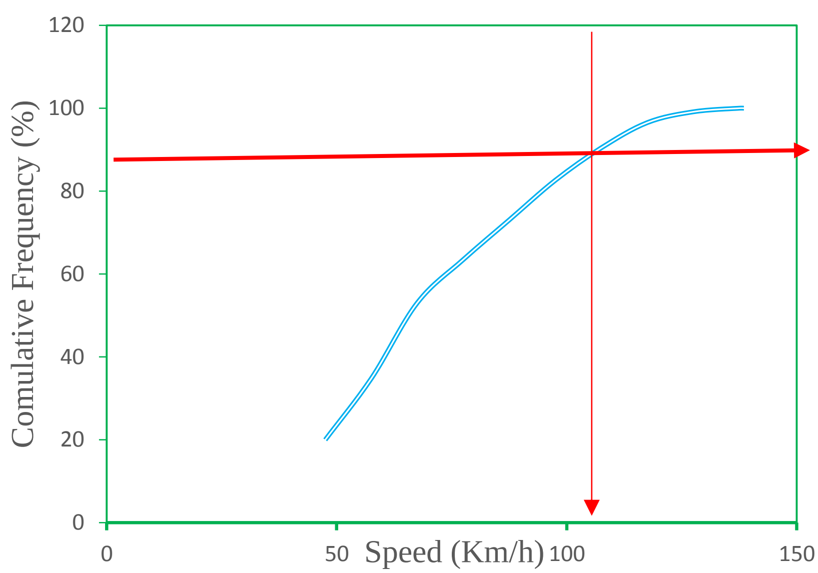

Fig 29: 85th percentile speed Tulubulo-Sebeta road segment

- 85th percentile speed of Tulubulo-Sebeta is 102 km/h

- Average speed of Tulubulo-Sebeta is 80.41 km/h

According to HCM 2010, the BFFS (speed limit+10mil/h) of selected road segments for this study by considering 85th as the speed limit are determined and presented in the following table 18.

Table 18: 85th percentile speed and BFFS

Segment	**Average speed**		**85th percentile speed/speed limit**		**BFFS(Km/h)or speed limit +10mil/h**	
	Km/h	**Mil/h**	**Km/h**	**Mil/h**	**Km/h**	**Mil/h**
Sululta- Chancho	76.78	47.6	85	52.70	91.2	63
Chancho-Sululta	77.92	48.30	88	54.56	94.2	65
Addis Ababa-Sendafa	81.26	50.38	98	60.76	104.2	71
Sendafa-Addis Ababa	81.6	50.60	95	58.90	101.2	69
Sebeta-Tulubulo	79.97	49.60	96	59.52	102.2	70
Tulubulo-Sebeta	80.41	49.85	102	63.24	108.2	73

However, the BFFS value in the HCM 2010 manual ranges from 45mil/h to 70 mil/h. Since, some of the values of BFFS calculated and shown in the above table 19 are out of the maximum value within the range of BFFS set in the HCM 2010 manual. Hence, maximum value of BFFS set in manual is adopted for the roads segment to simulate LOS using HCS 2010, which have value of BFFS exceed the maximum value set in HCM 2010 in the calculation of FFS for this study.

Ethiopia's Speed Limit Regulation (No.361/1969) which is still in use was enacted in 1969. According to the regulation, the maximum speed limits are 100, 70, and 60 km/hr for private cars and motorcycles, 80, 60, and 50 km/hr for commercial vehicles, 70, 50, and 40 km/hr for motor vehicles and trucks with semi-trailers and trailers on primary, secondary, and feeder roads respectively outside urban areas. Within urban areas, the speed limits are 60, 40, and 30 km/hr for private cars and motorcycles, single unit trucks with maximum gross weight of 3,500 kg and public transport vehicles, and single unit trucks exceeding 3,500 kg and trucks with trailers respectively (UNECA, 2009).

From speed collected in the field and calculated as shown in the above table 19, the 85th percentile of operating speed that considered as speed limit for the purpose of thesis ranges from 85km/h to 108km/h, which is almost all similar with Ethiopian speed limit for rural area regulation enacted in 1969.

Many researcher has explained that 85^{th} percentile of operating speed is the most appropriate value and adopt as speed limit in many countries. In this research, to simulate the LOS improvement, the 85^{th} percentile operating speed has been adopted as speed limit shown in the above 19 and BFFS considered as speed limit plus 10mil/h as stated in HCM 2010. Then, LOS improvement has been simulated in HCS 2010 software using the value of this BFFS. The result has been shown as follows in the table 19.

Table 19: LOS with proposed lane and shoulder width and after proposed improvement

Segment (5km between)	**Existing lane width(m)**	**Proposed lane width (m)**	**Existing shoulder width(m)**	**Proposed shoulder width(m)**	**PTSF with proposed lane and shoulder width (%)**	**ATS with proposed lane and shoulder width (mil/h)**	**LOS with proposed lane and shoulder width**
Sululta Chancho	3.5	3.66	1.5	3	74.7	49.7	D
Chancho-Sululta	3.5	3.66	1.5	3	73.6	51.6	D
AddisAbaba -Sendafa	3.5	3.66	1.5	3	42.7	63.1	B
Sendafa – Addis Ababa	3.5	3.66	1.5	3	44.4	61.7	B
Sebeta-Tulubulo	3.5	3.66	1.5	3	49.7	61.7	B
Tulubulp-Sebeta	3.5	3.66	1.5	3	52.3	62.1	C

As shown in the above table 19, the simulation result of HCS 2010 indicate that the Addis Ababa-Sendafa, Sendafa-Addis Ababa, and Sebeta-Tulubulo roads segment operate with desired LOS due to proposed improvement like increasing lane width, shoulder width and increasing free flow speed to the appropriate value to enhance LOS to the target level. As it was noted that the analysis result for current condition without any improvement, the LOS governed by ATS value for the selected roads segment except Sululta-Chancho, Chancho-

Sululta and Tulubulo-Sebeta in which LOS governed by both ATS and PTSF values. Since, the roads segment selected for this study are serving for mobility of goods and peoples and the highest speed is anticipated, the researcher suggested that the minimum LOS shall be B for flat and rolling terrain. LOS, more than B may not be economically acceptable for the exhibited traffic condition. However, to meet the intended purpose of those roads segment the LOS shall be at least B in the flat and rolling terrain. Thus, sufficient lane and shoulder width and other parameters that maximize the value of BFFS shall be provided via increasing the value of ATS for those roads segment, which LOS is governed by ATS value to improve LOS to the target value (i.e. LOS B for flat and rolling terrain). HCS 2010 simulation result also shows that for Chancho-Sululta, Sululta-Chancho, and Tulubulo –Sebeta roads segment, LOS fall in to desired level (I.e. LOS B) by providing the road element that modify both ATS and PTSF values like increasing lane and shoulder width, passing lane and increasing BFFS via providing the road element that have impact in the operating speed. Simulation results are shown in the following table 20.

Table 20: LOS with proposed lane, shoulder width, passing lane, and proposed improvement

Segment (5km between)	**Proposed lane width (m)**	**Proposed shoulder width(m)**	**Proposed passing lane length (mil)**	**PTSF with proposed lane and shoulder width and passing lane (%)**	**ATS with proposed lane and shoulder width and passing lane (mil/h)**	**LOS with proposed lane and shoulder width and passing lane**
Sululta Chancho	3.66	3	1.1	49.9	53.0	B
Chancho-Sululta	3.66	3	0.9	49.8	54.8	B
Tulubulp-Sebeta	3.66	3	0.8	38.0	63.8	B

To summarize, as shown in the previous analysis and result discussion section 4.1and 4.2 of this paper, LOS analysis has been carried out based on direct field measurement of the speed to estimate free flow speed for current and for the future five year. HCM 2010 manual strongly suggested that field measurement speed is appropriate estimation of free flow speed than estimate free flow speed based on BFFS value considering lane and shoulder width effect to the condition that the appropriate local knowledge is not available to fix the value of BFFS.

As result, the LOS analysis performed based on speed-measured in the field and the result shows that the roads segments selected for this study are operating with undesirable level of service.

To analysis LOS based on estimated free flow speed, it is required making sure that the appropriate value for BFFS shall be assigned. According to HCM 2010 manual, BFFS depends on the speed limit. The LOS analysis based on estimated free flow speed in Ethiopia as per prevailing filed condition may not be appropriate. Because, LOS analysis based on estimated free flow speed which related to the speed limit exhibited in the speed limit regulation might indicate appropriate result while the actual operating is in poor performance condition as well as the safety of the road might compromised due to unfavorable condition exhibited in the field. However, it is possible to simulate and predict the LOS improvement by assigning the desired value of the base free flow speed based of functional classification of the road and by providing the most appropriate geometrical elements that increase our confidence towards to achieve this anticipated operating speed without compromising the safety of the road.

In fact, the LOS result depends on traffic flow and operating speed. When the traffic flow increase and operating speed decrease, LOS reduced to undesirable level. Nonetheless, it is difficult to control the increment of traffic flow to improve LOS of the road to desired level. Hence, to improve LOS the only option is proving the appropriate georgic parameter that allows increasing vehicles operating speed without compromising the safety of the road. There are many geometrical elements, which already recommended by many researcher as performance-enhancing tools by increasing operating speed as the same time improve the safety of the road. These are:

- Sufficient lane and shoulder width
- Limited number of access point density
- Centerline and edge line marking
- Shorter distances between features that have influence on a driver’s speed
- Sufficient width of lateral clearance
- Speed limit

- Sufficient sight distance
- Sufficient curve radius
- Appropriate horizontal and vertical alignment
- Passing lane

In Ethiopia, the geometry of the road design is performed based on ERA design manual as guideline. In the manual, design elements, which have a direct relation with design speed, are lane width, shoulder width, horizontal curve radius, super-elevation, sight distance, and gradients. In the manual, it is also clearly stated that drivers adjust their speed to the physical limitation and prevailing traffic condition. Hence, different physical limitation has affect greatly operating speed. For horizontal alignment, design speed applies only to curves, not to the connecting tangents. Design speed has no practical meaning on tangents. As result, the operating speed on a tangent especially a long one, can significantly exceed the design speed of the road as a whole (ERA Manual, 2013).

The anticipated operating speed is often greater than posted speed limit in the rural mobility road. Design speed appears to have minimal impact on operating speeds unless a tight horizontal radius or a low K-value is present. Large variance in operating speed was found for a given inferred design speed on rural two-lane highways. On suburban horizontal curves, drivers operate at speeds in excess of the inferred design speed on curves designed for 43.5 mph (70 km/h) or less, while on rural two-lane roadways, drivers operate above the inferred design speed on curves designed for 55.9 mph (90 km/h) or less. When posted speed exceeds design speed, however, liability concerns arise even though drivers can safely exceed the design speed (Fitzpatrick et al, 2003). From this, it is noted that operating speed vehicles often greater than design speed and posted speed limit in good performance roads.

However, almost all except Sebeta-Tulubulo and Tulubulo-Sebeta road segment, calculated 85^{th} percentile of the speed for the 5km flat road segments selected for this study (without horizontal curve) are less than design speed. AADT of all road segment selected for this study fall under DC 6 design standard and design speed for flat terrain under this design standard is 100km/h. Furthermore, calculated 85^{th} percentile speed for this study also within the range speed limit while many researcher depicted that anticipated operating speed is more often greater than posted speed limit. The many researcher also depicted that speed limit influenced operating speed. Though the speed limit in Ethiopia enacted in the speed limit regulation, the implementation of speed limit is not to the appropriate level especially in the rural road. Hence, the speed limit has not more influenced for the lower operating speed exhibited for the selected road segments for this study. Thus, the cause for lower speed to be observed are most probably the physical limitation such as narrow lane and shoulder width, insufficient lateral clearance, absence of centerline and edge line marking and so on even lower traffic flow exhibited on the some road segments selected for this study, which the higher operating speed is expected than design speed. Driver behavior and presence of high proportion of heavy vehicles may also be other factor for the reduction of speed below the design speed in the tangent section of those segment selected for this study.

Therefore, the road agencies and the designer of the road should think over to minimize the physical limitation to maximize the operating speed in addition to design speed. Moreover, the Ethiopia's Speed Limit Regulation (No.361/1969) which is still in use was enacted in 1969 may become problematic from a safety point of view due to such physical limitation. The value set as speed limit in the speed limit regulation of Ethiopia is almost all equivalent to other countries speed limit like America (i.e. from 55mil/h to 65mil/h for rural road). Since, main intended purpose of the selected roads segment for this study is mobility with desired speed, the value of speed limit set in Ethiopia's Speed Limit Regulation (No.361/1969) by itself has not a problem. However, the problem is the road selected for this study has operated with undesirable LOS as depicted in the analysis result and discussion section 4.1 and 4.2 of this paper above and accident observed in many occasion.

Hence, to meet the intended purpose of the road, the road agencies should design the road with appropriate design standard with the appropriate prediction of operating speed using different prediction models rather than design speed only, through which the road to be operating with desired level of service and without compromising safety. To this end, the LOS of those roads segment selected for this study has been improved to desired level (i.e. minimum LOS B for flat terrain) by fixing the value of BFFS as 85^{th} percentile operating speed considered as speed limit plus 10 mil/h and increasing lane and shoulder width to the appropriate standard value. Table 20 and 21 above shows the LOS improvement observed from HCS 2010 software simulation output. Thus, to meet the target LOS (i.e. minimum LOS B for flat terrain) the speed limit should be the 85^{th} percentile operating speed value shown the in the table 19 above and lane and shoulder width should be the value set in table 20 above. To reduce the impact of 85^{th} percentile operating speed on the safety, it is expected from road agencies to provide sufficient lane and shoulder width, limited number of access point density, appropriate Centerline and edge line marking, sufficient width of lateral clearance, sufficient sight distance, sufficient curve radius, appropriate horizontal and vertical alignment.

From many researcher, it is also noted that majority of accident related with driver and pedestrian. It is also expected from road transport authorities to improve driver behaviors to reduce accident related to driver behaviors and enhance those roads segment performance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Based on the analysis result of Level of service for current , future 5 years and examination of effects of lane and shoulder width and other parameters that performed using HCS, 2010 software the following conclusion and recommendation has been derived.

6.1. CONCLUSION

- The study has performed LOS analysis for all roads segment selected for this thesis using speed data that measured in the field by Radar-Gun. The Result shows currently, all roads segment selected for this study are operating with undesirable levels of service between C and E. Both PTSF and ATS are applied as LOS measures for Class I highways. The ATS value has been fallen to the undesired category of LOS for some of roads segment while PTFS value has been fallen to the desired LOS. Thus, ATS value governs those roads segment are operating with undesirable LOS. Since, LOS governed by ATS value which reflect mobility, the mobility of those roads greatly affected. This implies the main purpose of those roads segments (i.e. mobility) is declined. The general LOS impact at this condition is level of comfort and convenience declined significantly at this level. Disruptions in the traffic stream, such as an incident for example, vehicular accident or disablement can result in significant queue formation and vehicular delay. Furthermore, Level of service at this condition mean freedom to maneuver is noticeably restricted, and lane changes required careful attention on the part of drivers.
- The study has proposed passing lane to improve LOS and checked the LOS improvement. The HCS 2010 software simulation result shows that by assigning 1km length-passing lane in to 5 km road segment to the current operating condition, LOS for some of the road segment is changed from one letter scheme to the next better letter schemes. However, as most of the roads segment's LOS governed by ATS value and since the provision of passing lane does not maximize the value of ATS significantly, the LOS improvement is not to desired

level due to passing lane. From simulation result of HCS 2010, it is also noted that provision of passing lane is important to reduce PTSF value more than to increase ATS value. Hence, passing lane is advisable for the roads segment for those whose LOS governed by PTSF value. Furthermore, LOS in terms of letter scheme A to F may or might change based on ATS and PTSF threshold values. If the ATS value for without passing lane condition approaches to the highest margin and PTSF value approaches to the lowest marginal value, then the LOS with passing lane has a tendency to change to the next better LOS letter scheme. However, overall LOS improvement to the desired level is not observed except travel time saving during peak hour flow, due to passing lane provision in two-lane, two-way road. Therefore, passing lane provision has advantage to improve LOS only for those roads segment, which have highest PTFS value, and LOS governed by this PTSF value and even level of improvement is not much significant.

- LOS analysis of using HCS 2010 software simulation for the future five year shows that all selected road segment will operate with almost all to the similar condition to current condition at the end of target year. ATS is still govern for all most all roads segments for the future five year. LOS improvement also simulated using HCS 2010 software by assigning the 1km length-passing lane and found that LOS in terms of letter scheme A to F is not changed significantly except some of roads segment. However, it is observed that for peak hour flow of traffic increase , the travel time saving with provision of passing lane with two-lane, two-way road also significantly increase.
- Many researcher has explained that 85^{th} percentile of operating speed is the most appropriate value and adopt as speed limit in many countries. In this research, the researcher has computed the 85^{th} percentile operating speed and adopted as speed limit to compute BFFS. BFFS has been computed by adding 10 mil/h in to 85^{th} percentile operating speed. By using BFFS that obtained from 85^{th} percentile operating speed and by changing lane width from 3.5m to 3.66m and shoulder width from 1.5m to 3m, LOS simulation has been performed. The result obtained from this simulation shows that LOS for Addis Ababa-Sendafa, Sendafa-Addis

Ababa, and Sebeta-Tulubulo roads segment has been fallen in to B. However, by using BFFS that obtained from 85th percentile operating speed and by changing lane width from 3.5m to 3.66m and shoulder width from 1.5m to 3m, LOS for Sululta-Chancho, Chancho-Sululta, and Tulubulo-Sebeta still has been fallen in undesired level as LOS governed by both ATS and PTSF values. To improve the LOS of those roads segment, the researcher has assigned passing lane and simulated in to HCS 2010. LOS has been fallen in to B category by using 3.66 m lane width , 3m shoulder width , 0.8mil passing lane for Chancho-Sululta, 0.9mil passing lane for Sululta – Chancho and 1.1 mil passing lane for Tulubulo-Sebeta roads segment.

- As mentioned above, LOS has been simulated in to HCS 2010 software by using 85th operating speed and by assigning sufficient lane, shoulder width and passing lane and exhibited that LOS has been fallen in to B category. In this case, LOS improved to desired level. However, adopting this 85th operating speed as speed limit based on prevailing field condition, may compromise the safety of the those roads. Hence, to reduce the impact of 85th percentile operating speed on the safety, it is expected from road agencies to provide limited number of access point density, appropriate Centerline and edge line marking, sufficient width of lateral clearance, sufficient sight distance, sufficient curve radius, appropriate horizontal and vertical alignment in addition to Lane, shoulder and passing lane.

6.2. RECOMMENDATION

- To meet the intended purpose (i.e. mobility) of those roads in which highest speed is expected, roads agencies intervention is highly required by designing and implementing the appropriate geometric parameter to enhance ATS value for those roads segment which LOS governed by ATS value. LOS depends on traffic volume and operating speed. To improve LOS to the desired level for those roads, which the LOS governs by ATS value, the only option is providing the appropriate geometric parameters, which maximize the ATS, as it is difficult to control increment of traffic flow. Therefore, creating different prediction models of operating speed as well as adopting already created prediction models is required to predict the operating speed of those roads during operation period and to predict the desired LOS.
- Even though the riding quality of those two-lane, two-way roads segments are in good condition, LOS decline from time to time and travel time highly affected due to increasing the volume of traffic and proportion of truck. In this regard, appropriate geometric parameters design such as increasing lane and shoulder width and provision of passing lane is required to improve LOS to desired level. The most important concern in the design of the road is maintaining the capacity, LOS, and safety requirements of roads. Therefore, the researcher suggest that future further research is needed to show the safety effectiveness of those geometric properties of roads in addition to LOS improvement by developing data base systems that used to collect and organized site specific accident data. By taking in to account cost saving due to from travel time saving and accident reduction, feasibility study is recommended to provide the appropriate geometric parameters.
- In many ERA project, during feasibility study travel time saving related with roughness has taken in to consideration as benefit with project case scenario which means travel time saving is one of contribution factor for the decision maker whether the project is viable or not . Hence, as the passing lane provision has effect on the travel time saving specially for high traffic flow is expected due to project development, travel time saving from passing lane provision shall be taken in to account in the feasibility study of project as alternative.

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APPENDICES

APPENDEX A: Traffic Data from ERA count

ANNUAL AVERAGE DAILY TRAFFIC BY ROAD SECTION

Rote No.			Length	Car	Land Rover	Small Bus	Large Buse	Small Truck	Meduim Truck	Heavy Truck	Truck & Trailer	Total
Traffic Year 2002												
1	ADDIS ABABA	DEBRE BERHAN	130	50	121	185	97	102	152	153	92	952
2	ADDIS ABABA	Comando	113	34	109	161	71	93	66	151	51	736
3	ADDIS ABABA	Ghion	116	100	235	445	191	89	238	105	89	1492
Total				184	465	791	359	284	456	409	232	3180
Traffic Year 2003												
1	ADDIS ABABA	DEBRE BERHAN	130	34	119	193	91	92	140	109	66	844
2	ADDIS ABABA	Comando	113	48	118	211	73	107	106	113	73	849
3	ADDIS ABABA	Ghion	116	82	260	493	196	115	269	146	118	1679
Total				164	497	897	360	314	515	368	257	3372
Traffic Year 2004												
1	ADDIS ABABA	DEBRE BERHAN	130	39	126	205	103	136	181	137	92	1019
2	ADDIS ABABA	Comando	113	45	125	234	85	111	154	104	85	943
3	ADDIS ABABA	Ghion	116	117	325	565	234	80	301	112	95	1829
Total				201	576	1004	422	327	636	353	272	3791
Traffic Year 2005												
1	ADDIS ABABA	DEBRE BERHAN	130	33	100	184	94	114	173	120	109	927
2	ADDIS ABABA	Comando	113	53	126	234	79	114	187	72	70	935
3	ADDIS ABABA	Ghion	116	113	254	453	180	79	315	80	68	1542
Total				199	480	871	353	307	675	272	247	3404
Traffic Year 2006												
1	ADDIS ABABA	DEBRE BERHAN	130	43	165	214	118	156	210	144	76	1126
2	ADDIS ABABA	Comando	113	87	171	352	95	151	308	158	106	1428
3	ADDIS ABABA	Ghion	116	90	254	430	186	54	345	114	87	1560
Total				220	590	996	399	361	863	416	269	4114
Traffic Year 2007												
1	ADDIS ABABA	DEBRE BERHAN	130	46	216	247	147	161	202	151	67	1237
2	ADDIS ABABA	Comando	113	113	173	428	142	219	245	170	149	1639
3	ADDIS ABABA	Ghion	116	227	378	618	314	223	497	243	158	2658
Total				386	767	1293	603	603	944	564	374	5534
Traffic Year 2008												
1	ADDIS	DEBRE	130	48	156	265	173	157	324	224	111	1458

	ABABA	BERHAN										
2	ADDIS ABABA	Comando	113	83	155	472	120	219	196	143	146	1534
3	ADDIS ABABA	Ghion	116	240	542	758	130	115	508	357	72	2722
Total				371	853	1495	423	491	1028	724	329	5714
Traffic Year 2009												
1	ADDIS ABABA	DEBRE BERHAN	130	39	173	278	188	123	263	191	80	1335
2	ADDIS ABABA	Comando	113	106	254	575	118	364	423	335	222	2397
3	ADDIS ABABA	Ghion	116	316	562	885	126	148	603	470	69	3179
Total				461	989	1738	432	635	1289	996	371	6911
Traffic Year 2010												
1	ADDIS ABABA	DEBRE BERHAN	130	51	190	320	157	172	344	217	102	1553
2	ADDIS ABABA	Comando	113	116	284	633	131	225	338	268	134	2129
3	ADDIS ABABA	Ghion	116	283	523	843	117	140	580	375	72	2933
Total				450	997	1796	405	537	1262	860	308	6615
Traffic Year 2011												
1	ADDIS ABABA	DEBRE BERHAN	130	77	366	252	107	193	296	188	68	1547
2	ADDIS ABABA	Comando	113	130	287	505	237	318	380	334	256	2447
3	ADDIS ABABA	Ghion	116	199	634	1248	213	284	749	514	118	3959
Total				406	1287	2005	557	795	1425	1036	442	7953
Traffic Year 2012												
1	ADDIS ABABA	DEBRE BERHAN	130	99	175	497	113	192	309	228	66	1679
2	ADDIS ABABA	Comando	113	110	240	412	174	266	251	234	230	1917
3	ADDIS ABABA	Ghion	116	268	419	765	187	252	521	337	194	2943
Total				477	834	1674	474	710	1081	799	490	6539
Traffic Year 2013												
1	ADDIS ABABA	DEBRE BERHAN	130	113	257	421	172	296	427	335	182	2203
2	ADDIS ABABA	Comando	113	105	290	553	188	302	344	327	336	2445
3	ADDIS ABABA	Ghion	116	400	527	821	338	488	671	495	424	4164
Total				618	1074	1795	698	1086	1442	1157	942	8812
Traffic Year 2014												
1	ADDIS ABABA	DEBRE BERHAN	130	120	213	432	150	236	332	235	152	1870
2	ADDIS ABABA	Comando	113	115	485	635	296	509	614	533	552	3739
3	ADDIS ABABA	Ghion	116	465	704	918	382	567	814	645	645	5140
Total				700	1402	1985	828	1312	1760	1413	1349	10749
Traffic Year 2015												
1	ADDIS ABABA	DEBRE BERHAN	130	125	194	434	155	244	327	244	98	1821
2	ADDIS	Comando	113	94	407	568	281	520	605	527	576	3578

	ABABA											
3	ADDIS ABABA	Ghion	116	628	970	1258	560	758	1075	851	684	6784
Total				847	1571	2260	996	1522	2007	1622	1358	12183

AVERAGE DAILY TRAFFIC SUMMARISED BY DISTRICT														
Cycle	Reported Year	Direction		Car	Land Rover	Small Buss	Large Buss	Small truck	Meduim Truck	Heavy Truck	Truck Trailer	Total	15% ADT	% truck
		From	To											
1	2002	Sendafa	Adis Abeba	79	129	301	139	170	210	194	141	1,363.00	204	52
		Addis Abeba	Sendafa	80	134	287	136	174	211	198	135	1,355.00	203	53
		CHANCHO	Addis Abeba	38	99	185	72	88	47	105	43	677.00	102	42
		Addis Abeba	CHANCHO	38	100	206	72	87	41	101	42	687.00	103	39
		sebeta	TULU BOLO	15	69	115	80	58	135	74	63	609.00	91	54
		TULU BOLO	sebeta	15	76	136	84	59	143	75	66	654.00	98	52
2		Sendafa	Adis Abeba	79	121	315	125	184	275	293	149	1,541.00	231	58
		Addis Abeba	Sendafa	99	137	270	120	173	256	287	147	1,489.00	223	58
		CHANCHO	Addis Abeba	36	80	168	75	87	60	110	44	660.00	99	46
		Addis Abeba	CHANCHO	37	78	200	75	86	61	108	44	689.00	103	43
		sebeta	TULU BOLO	7	70	123	94	36	95	49	38	512.00	77	43
		TULU BOLO	sebeta	8	73	148	97	45	108	61	40	580.00	87	44
3		Sendafa	Adis Abeba	74	129	230	96	172	231	178	136	1,246.00	187	58
		Addis Abeba	Sendafa	87	137	210	93	157	218	171	124		180	

												1,197.00		56
		CHANCHO	Addis Abeba	53	118	200	74	55	77	133	61	771.00	116	42
		Addis Abeba	CHANCHO	49	119	239	74	52	80	131	58	802.00	120	40
		sebeta	TULU BOLO	9	106	168	80	69	181	154	41	808.00	121	55
		TULU BOLO	sebeta	9	118	211	82	71	201	170	41	903.00	135	53
		Sendafa	Adis Abeba									-	0	-
		Addis Abeba	Sendafa									-	0	-
		CHANCHO	Addis Abeba	64	124	253	75	104	94	122	56	892.00	134	42
		Addis Abeba	CHANCHO	60	124	278	74	96	92	109	55	888.00	133	40
		sebeta	TULU BOLO	7	87	144	100	50	125	81	44	638.00	96	47
1		TULU BOLO	sebeta	9	94	176	104	54	139	85	43	704.00	106	46
	2003	Sendafa	Adis Abeba	66	126	307	119	186	243	170	113	1,330.00	200	54
		Addis Abeba	Sendafa	65	134	282	116	176	234	162	111	1,280.00	192	53
		CHANCHO	Addis Abeba	52	118	193	73	244	98	116	66	960.00	144	55
		Addis Abeba	CHANCHO	53	122	243	74	94	104	111	66	867.00	130	43
		sebeta	TULU BOLO	13	157	233	89	92	220	219	38	1,061.00	159	54
2		TULU BOLO	sebeta	15	178	277	97	122	550	263	41	1,543.00	231	63

		Sendafa	Adis Abeba	41	111	318	68	100	231	72	50	991.00	149	46
		Addis Abeba	Sendafa	39	111	265	64	99	223	74	53	928.00	139	48
		CHANCHO	Addis Abeba	56	124	224	70	90	117	108	68	857.00	129	45
		Addis Abeba	CHANCHO	57	130	274	70	94	120	106	68	919.00	138	42
		sebeta	TULU BOLO	9	137	171	93	92	175	125	30	832.00	125	51
3		TULU BOLO	sebeta	9	148	232	101	83	210	146	34	963.00	144	49
		Sendafa	Adis Abeba	51	119	296	115	177	227	165	111	1,261.00	189	54
		Addis Abeba	Sendafa	49	137	274	111	170	229	160	103	1,233.00	185	54
		CHANCHO	Addis Abeba	58	127	233	97	95	111	98	79	898.00	135	43
		Addis Abeba	CHANCHO	56	126	283	96	93	110	93	72	929.00	139	40
		sebeta	TULU BOLO	17	205	336	140	51	270	205	47	1,271.00	191	45
1	2004	TULU BOLO	sebeta	17	209	376	144	47	283	204	47	1,327.00	199	44
		Sendafa	Adis Abeba	62	127	354	106	219	292	215	126	1,501.00	225	57
		Addis Abeba	Sendafa	61	146	336	102	210	277	207	129	1,468.00	220	56
		CHANCHO	Addis Abeba	52	114	282	88	131	209	120	82	1,078.00	162	50
		Addis Abeba	CHANCHO	52	112	321	88	142	211	114	81	1,121.00	168	49
2		sebeta	TULU BOLO	14	171	284	92	56	242	162	54		161	

												1,075.00		48
		TULU BOLO	sebeta	18	182	309	94	58	243	157	56	1,117.00	168	46
		Sendafa	Adis Abeba	74	149	327	103	196	271	199	122	1,441.00	216	55
		Addis Abeba	Sendafa	73	157	309	96	196	262	195	118	1,406.00	211	55
		CHANCHO	Addis Abeba	54	145	286	72	81	224	113	108	1,083.00	162	49
		Addis Abeba	CHANCHO	54	146	312	73	79	228	106	96	1,094.00	164	47
		sebeta	TULU BOLO	14	128	137	90	40	213	79	53	754.00	113	51
3		TULU BOLO	sebeta	16	136	164	102	45	218	87	55	823.00	123	49
		Sendafa	Adis Abeba	66	114	370	117	194	257	200	116	1,434.00	215	53
		Addis Abeba	Sendafa	69	124	362	115	192	241	192	116	1,411.00	212	53
		CHANCHO	Addis Abeba	83	155	300	90	96	212	75	115	1,126.00	169	44
		Addis Abeba	CHANCHO	76	156	341	88	97	223	70	97	1,148.00	172	42
	2005	sebeta	TULU BOLO	12	78	253	102	69	254	105	43	916.00	137	51
1		TULU BOLO	sebeta	15	90	290	109	76	260	113	45	998.00	150	49
		Sendafa	Adis Abeba	63	120	380	105	175	289	160	105	1,397.00	210	52
		Addis Abeba	Sendafa	59	136	345	101	164	275	160	103	1,343.00	201	52
2		CHANCHO	Addis Abeba	74	128	314	97	148	279	109	81	1,230.00	185	50

		Addis Abeba	CHANCHO	80	146	346	97	157	283	101	73	1,283.00	192	48
		sebeta	TULU BOLO	21	203	233	82	55	317	85	47	1,043.00	156	48
		TULU BOLO	sebeta	21	218	270	86	54	332	92	50	1,123.00	168	47
		Sendafa	Adis Abeba	22	38	73	29	41	75	30	37	345.00	52	53
		Addis Abeba	Sendafa	25	27	69	15	33	92	27	17	305.00	46	55
		CHANCHO	Addis Abeba	32	90	182	36	54	182	38	36	650.00	98	48
		Addis Abeba	CHANCHO	33	92	187	34	52	184	42	35	659.00	99	47
		sebeta	TULU BOLO	9	83	177	38	55	213	69	42	686.00	103	55
3		TULU BOLO	sebeta	11	90	202	41	62	221	69	46	742.00	111	54
		Sendafa	Adis Abeba	75	117	316	111	122	317	163	87	1,308.00	196	53
		Addis Abeba	Sendafa	66	109	292	107	108	290	145	87	1,204.00	181	52
		CHANCHO	Addis Abeba	104	194	382	93	127	334	173	92	1,499.00	225	48
	2006	Addis Abeba	CHANCHO	104	203	428	93	144	385	171	93	1,621.00	243	49
		sebeta	TULU BOLO	32	215	301	80	32	342	110	76	1,188.00	178	47
1		TULU BOLO	sebeta	33	236	335	82	35	385	125	81	1,312.00	197	48
		Sendafa	Adis Abeba	16	181	130	90	141	71	101	36	766.00	115	46
2		Addis Abeba	Sendafa	72	148	294	140	176	368	194	109		225	

												1,501.00		56
		CHANCHO	Addis Abeba	87	187	377	100	146	401	226	145	1,669.00	250	55
		Addis Abeba	CHANCHO	87	196	431	101	158	410	218	144	1,745.00	262	53
		sebeta	TULU BOLO	23	172	276	70	50	350	129	53	1,123.00	168	52
		TULU BOLO	sebeta	24	194	311	70	59	375	142	56	1,231.00	185	51
		Sendafa	Adis Abeba	74	167	321	120	221	325	212	126	1,566.00	235	56
		Addis Abeba	Sendafa	84	181	293	113	223	330	216	146	1,586.00	238	58
		CHANCHO	Addis Abeba	77	197	269	104	120	240	115	78	1,200.00	180	46
		Addis Abeba	CHANCHO	82	198	296	107	120	246	109	72	1,230.00	185	44
		sebeta	TULU BOLO	37	250	296	156	43	356	163	119	1,420.00	213	48
3		TULU BOLO	sebeta	40	278	328	165	47	383	176	134	1,551.00	233	48
		Sendafa	Adis Abeba	66	273	296	159	257	181	171	74	1,477.00	222	46
		Addis Abeba	Sendafa	61	280	281	153	257	190	173	75	1,470.00	221	47
	2007	CHANCHO	Addis Abeba	145	190	434	212	241	436	329	218	2,205.00	331	56
		Addis Abeba	CHANCHO	134	182	462	210	246	442	329	211	2,216.00	332	55
		sebeta	TULU BOLO	73	282	372	99	32	493	125	57	1,533.00	230	46
1		TULU BOLO	sebeta	74	291	421	101	34	519	127	56	1,623.00	243	45

		Sendafa	Adis Abeba	67	255	286	135	239	164	167	97	1,410.00	212	47
		Addis Abeba	Sendafa	66	252	271	128	224	158	173	101	1,373.00	206	48
		CHANCHO	Addis Abeba	83	176	431	137	226	149	85	104	1,391.00	209	41
		Addis Abeba	CHANCHO	55	170	352	123	217	147	83	104	1,251.00	188	44
		sebeta	TULU BOLO	53	229	264	161	44	285	103	40	1,179.00	177	40
2		TULU BOLO	sebeta	53	229	264	161	44	285	103	40	1,179.00	177	40
		Sendafa	Adis Abeba	88	294	269	142	262	179	199	96	1,529.00	229	48
		Addis Abeba	Sendafa	88	309	270	140	254	181	201	95	1,538.00	231	48
		CHANCHO	Addis Abeba	130	164	428	102	185	203	130	142	1,484.00	223	44
		Addis Abeba	CHANCHO	125	158	464	97	193	209	130	126	1,502.00	225	44
		sebeta	TULU BOLO	41	199	322	74	79	345	146	58	1,264.00	190	50
3		TULU BOLO	sebeta	46	220	363	79	86	355	149	58	1,356.00	203	48
		Sendafa	Adis Abeba	64	141	201	216	174	247	193	130	1,366.00	205	54
		Addis Abeba	Sendafa	64	141	192	215	169	242	193	130	1,346.00	202	55
	2008	CHANCHO	Addis Abeba	61	131	304	147	207	248	200	179	1,477.00	222	56
		Addis Abeba	CHANCHO	56	124	302	146	218	241	198	169	1,454.00	218	57
1		sebeta	TULU BOLO	38	187	421	85	149	285	142	42		202	

												1,349.00		46
		TULU BOLO	sebeta	43	197	445	84	161	282	152	42	1,406.00	211	45
		Sendafa	Adis Abeba	71	246	377	233	323	404	301	207	2,162.00	324	57
		Addis Abeba	Sendafa	75	282	339	228	326	398	309	208	2,165.00	325	57
		CHANCHO	Addis Abeba	100	148	535	102	216	206	182	155	1,644.00	247	46
		Addis Abeba	CHANCHO	97	144	570	102	223	225	174	146	1,681.00	252	46
		sebeta	TULU BOLO	46	284	459	87	63	335	153	101	1,528.00	229	43
2		TULU BOLO	sebeta	49	302	513	90	70	376	164	104	1,668.00	250	43
		Sendafa	Adis Abeba	60	174	412	85	210	325	250	53	1,569.00	235	53
		Addis Abeba	Sendafa	56	169	386	81	203	330	248	52	1,525.00	229	55
		CHANCHO	Addis Abeba	97	151	512	100	161	184	129	141	1,475.00	221	42
		Addis Abeba	CHANCHO	96	153	551	107	192	194	125	131	1,549.00	232	41
		sebeta	TULU BOLO	41	327	465	99	25	410	273	59	1,699.00	255	45
3		TULU BOLO	sebeta	47	340	470	98	25	376	261	54	1,671.00	251	43
		Sendafa	Adis Abeba	44	132	379	143	147	264	148	75	1,332.00	200	48
	2009	Addis Abeba	Sendafa	33	120	233	129	126	230	145	73	1,089.00	163	53
1		CHANCHO	Addis Abeba	94	229	452	143	307	167	117	134	1,643.00	246	44

		Addis Abeba	CHANCHO	72	198	377	120	275	144	92	109	1,387.00	208	45
		sebeta	TULU BOLO	51	217	539	66	34	454	200	57	1,618.00	243	46
		TULU BOLO	sebeta	58	253	623	73	38	487	207	55	1,794.00	269	44
		Sendafa	Adis Abeba	56	261	348	243	276	375	286	160	2,005.00	301	55
		Addis Abeba	Sendafa	55	262	334	221	279	375	286	158	1,970.00	296	56
		CHANCHO	Addis Abeba	98	422	678	125	644	943	871	391	4,172.00	626	68
		Addis Abeba	CHANCHO	108	376	687	141	544	893	831	354	3,934.00	590	67
		sebeta	TULU BOLO	48	228	528	95	86	325	194	44	1,548.00	232	42
2		TULU BOLO	sebeta	53	263	588	99	108	342	188	45	1,686.00	253	41
		Sendafa	Adis Abeba	90	356	511	103	108	322	177	86	1,753.00	263	40
		Addis Abeba	Sendafa	69	329	522	95	96	295	166	88	1,660.00	249	39
		CHANCHO	Addis Abeba	122	250	599	104	391	491	326	256	2,539.00	381	58
		Addis Abeba	CHANCHO	114	247	598	100	376	468	298	249	2,450.00	368	57
		sebeta	TULU BOLO	40	214	499	48	52	346	207	49	1,455.00	218	45
3		TULU BOLO	sebeta	46	231	574	51	51	357	199	49	1,558.00	234	42
	2010	Sendafa	Adis Abeba	52	387	234	123	216	336	247	34	1,629.00	244	51
1		Addis Abeba	Sendafa	46	353	228	120	207	323	250	33		234	

												1,560.00		52
		CHANCHO	Addis Abeba	141	379	654	128	13	407	403	74	2,199.00	330	41
		Addis Abeba	CHANCHO	133	394	731	125	18	418	333	62	2,214.00	332	38
		sebeta	TULU BOLO	60	193	541	78	106	273	132	63	1,446.00	217	40
		TULU BOLO	sebeta	64	203	577	80	113	299	142	65	1,543.00	231	40
		Sendafa	Adis Abeba	91	283	450	229	331	498	349	196	2,427.00	364	57
		Addis Abeba	Sendafa	93	287	417	206	299	446	320	182	2,250.00	338	55
		CHANCHO	Addis Abeba	137	243	653	128	224	305	271	157	2,118.00	318	45
		Addis Abeba	CHANCHO	135	241	695	123	236	318	260	136	2,144.00	322	44
		sebeta	TULU BOLO	39	210	641	49	95	614	559	42	2,249.00	337	58
2		TULU BOLO	sebeta	41	233	765	51	104	768	632	46	2,640.00	396	59
		Sendafa	Adis Abeba	129	332	445	245	387	495	390	240	2,663.00	399	57
		Addis Abeba	Sendafa	137	367	425	240	356	493	388	234	2,640.00	396	56
		CHANCHO	Addis Abeba	114	205	726	106	251	444	379	160	2,385.00	358	52
		Addis Abeba	CHANCHO	118	211	771	108	247	401	312	129	2,297.00	345	47
		sebeta	TULU BOLO	49	301	492	45	39	265	118	45	1,354.00	203	34
3		TULU BOLO	sebeta	53	330	515	46	40	291	128	46	1,449.00	217	35

		Sendafa	Adis Abeba	101	481	279	114	239	406	252	78	1,950.00	293	50
		Addis Abeba	Sendafa	95	441	270	109	222	384	245	77	1,843.00	276	50
		CHANCHO	Addis Abeba	131	245	801	182	276	413	388	284	2,720.00	408	50
		Addis Abeba	CHANCHO	129	224	772	178	269	405	369	283	2,629.00	394	50
		sebeta	TULU BOLO	71	342	849	71	52	564	198	57	2,204.00	331	40
1		TULU BOLO	sebeta	98	392	959	70	55	630	188	63	2,455.00	368	38
		Sendafa	Adis Abeba	126	711	228	119	280	403	301	59	2,227.00	334	47
		Addis Abeba	Sendafa	112	646	227	115	247	368	294	57	2,066.00	310	47
	2011	CHANCHO	Addis Abeba	73	109	329	128	129	316	269	279	1,632.00	245	61
		Addis Abeba	CHANCHO	63	99	353	140	140	322	284	305	1,706.00	256	62
		sebeta	TULU BOLO	53	465	695	61	80	325	227	114	2,020.00	303	37
2		TULU BOLO	sebeta	60	330	754	60	71	348	228	99	1,950.00	293	38
		Sendafa	Adis Abeba	101	657	259	97	219	411	283	56	2,083.00	312	47
		Addis Abeba	Sendafa	98	617	250	92	215	400	281	56	2,009.00	301	47
		CHANCHO	Addis Abeba	268	387	604	392	420	425	405	392	3,293.00	494	50
		Addis Abeba	CHANCHO	257	367	395	378	401	408	342	366	2,914.00	437	52
3		sebeta	TULU BOLO	56	283	864	101	90	316	253	61		304	

												2,024.00		36
		TULU BOLO	sebeta	63	300	999	105	92	340	259	58	2,216.00	332	34
1	2012	Sendafa	Adis Abeba	113	234	723	127	214	381	276	51	2,119.00	318	44
		Addis Abeba	Sendafa	113	224	777	119	197	364	275	49	2,118.00	318	42
		CHANCHO	Addis Abeba	138	339	511	291	246	280	255	277	2,337.00	351	45
		Addis Abeba	CHANCHO	98	226	219	191	194	250	325	247	1,750.00	263	58
		sebeta	TULU BOLO	94	404	934	61	35	599	219	67	2,413.00	362	38
		TULU BOLO	sebeta	80	414	926	63	35	542	229	67	2,356.00	353	37
2		Sendafa	Adis Abeba	132	175	728	115	230	384	378	59	2,201.00	330	48
		Addis Abeba	Sendafa	119	163	697	105	201	355	361	58	2,059.00	309	47
		CHANCHO	Addis Abeba	183	281	425	264	285	281	287	361	2,367.00	355	51
		Addis Abeba	CHANCHO	248	321	377	315	359	345	390	420	2,775.00	416	55
		sebeta	TULU BOLO	69	394	562	73	52	418	146	90	1,804.00	271	39
		TULU BOLO	sebeta	72	413	610	79	55	457	167	89	1,942.00	291	40
3		Sendafa	Adis Abeba	149	147	609	122	223	359	308	69	1,986.00	298	48
		Addis Abeba	Sendafa	142	146	579	116	207	376	299	68	1,933.00	290	49
		CHANCHO	Addis Abeba	100	164	557	111	227	262	226	218	1,865.00	280	50

		Addis Abeba	CHANCHO	97	158	569	107	232	258	233	161	1,815.00	272	49
		sebeta	TULU BOLO	52	290	616	53	59	417	236	55	1,778.00	267	43
		TULU BOLO	sebeta	58	293	650	54	63	448	267	61	1,894.00	284	44
		Sendafa	Adis Abeba	226	340	630	221	386	538	523	265	3,129.00	469	55
		Addis Abeba	Sendafa	190	311	608	193	360	496	513	240	2,911.00	437	55
		CHANCHO	Addis Abeba	120	171	646	118	240	255	293	317	2,160.00	324	51
		Addis Abeba	CHANCHO	121	159	686	146	260	258	227	197	2,054.00	308	46
		sebeta	TULU BOLO	72	161	592	263	221	408	265	153	2,135.00	320	49
1		TULU BOLO	sebeta	73	176	564	258	215	396	267	154	2,103.00	315	49
	2013	Sendafa	Adis Abeba	136	356	434	253	370	507	429	283	2,768.00	415	57
		Addis Abeba	Sendafa	125	345	407	232	359	489	401	285	2,643.00	396	58
		CHANCHO	Addis Abeba	100	298	484	226	232	459	504	602	2,905.00	436	62
		Addis Abeba	CHANCHO	104	269	477	229	216	348	359	374	2,376.00	356	55
		sebeta	TULU BOLO	63	341	587	66	94	386	121	105	1,763.00	264	40
2		TULU BOLO	sebeta	66	387	636	87	93	425	125	103	1,922.00	288	39
		Sendafa	Adis Abeba	152	435	596	256	563	935	760	354	4,051.00	608	64
3		Addis Abeba	Sendafa	138	365	476	231	428	595	507	276		452	

												3,016.00		60
		CHANCHO	Addis Abeba	138	559	569	345	442	557	587	540	3,737.00	561	57
		Addis Abeba	CHANCHO	118	473	556	294	477	584	585	424	3,511.00	527	59
		sebeta	TULU BOLO	53	236	544	63	120	378	282	70	1,746.00	262	49
		TULU BOLO	sebeta	55	258	616	67	138	414	321	74	1,943.00	291	49
		Sendafa	Adis Abeba	178	250	551	234	284	476	279	261	2,513.00	377	52
		Addis Abeba	Sendafa	158	226	527	186	265	449	264	268	2,343.00	351	53
		CHANCHO	Addis Abeba	140	728	805	433	691	888	830	1025	5,540.00	831	62
		Addis Abeba	CHANCHO	145	726	761	402	602	821	904	677	5,038.00	756	60
		sebeta	TULU BOLO	50	321	571	44	37	227	130	85	1,465.00	220	33
1	2014	TULU BOLO	sebeta	56	351	632	44	40	275	139	88	1,625.00	244	33
		Sendafa	Adis Abeba	161	299	570	207	364	429	389	170	2,589.00	388	52
		Addis Abeba	Sendafa	149	288	561	202	357	431	378	172	2,538.00	381	53
		CHANCHO	Addis Abeba	120	560	582	445	714	864	829	665	4,779.00	717	64
		Addis Abeba	CHANCHO	119	634	669	410	602	847	807	578	4,666.00	700	61
		sebeta	TULU BOLO	60	322	498	44	34	332	111	94	1,495.00	224	38
2		TULU BOLO	sebeta	71	400	664	47	43	428	139	117	1,909.00	286	38

		Sendafa	Adis Abeba	171	293	482	197	316	438	342	264	2,503.00	375	54
		Addis Abeba	Sendafa	163	281	469	185	313	412	336	260	2,419.00	363	55
		CHANCHO	Addis Abeba	82	244	461	207	291	483	468	479	2,715.00	407	63
		Addis Abeba	CHANCHO	78	229	399	246	274	385	385	323	2,319.00	348	59
		sebeta	TULU BOLO	70	287	551	55	59	485	422	133	2,062.00	309	53
3		TULU BOLO	sebeta	73	298	615	53	54	468	414	132	2,107.00	316	51
		Sendafa	Adis Abeba	164	282	583	201	320	446	374	104	2,474.00	371	50
		Addis Abeba	Sendafa	144	268	533	181	290	432	345	103	2,296.00	344	51
		CHANCHO	Addis Abeba	60	394	530	368	688	871	928	928	4,767.00	715	72
		Addis Abeba	CHANCHO	42	290	433	331	480	623	671	595	3,465.00	520	68
		sebeta	TULU BOLO	88	370	812	46	36	582	147	157	2,238.00	336	41
1	2015	TULU BOLO	sebeta	94	388	841	49	40	597	158	162	2,329.00	349	41
		Sendafa	Adis Abeba	251	228	784	163	329	395	288	79	2,517.00	378	43
		Addis Abeba	Sendafa	251	228	784	163	329	395	288	79	2,517.00	378	43
		CHANCHO	Addis Abeba	147	626	677	382	631	802	769	777	4,811.00	722	62
		Addis Abeba	CHANCHO	140	604	629	387	526	828	843	829	4,786.00	718	63
2		sebeta	TULU BOLO	66	280	657	48	69	307	206	101		260	

												1,734.00		39
		TULU BOLO	sebeta	70	310	819	48	84	391	250	121	2,093.00	314	40
		Sendafa	Adis Abeba	165	282	481	316	383	514	499	214	2,854.00	428	56
		Addis Abeba	Sendafa	149	259	431	297	348	485	477	201	2,647.00	397	57
		CHANCHO	Addis Abeba	65	398	514	309	513	666	655	653	3,773.00	566	66
		Addis Abeba	CHANCHO	76	352	527	329	510	603	637	571	3,605.00	541	64
		TULU BOLO	GHYON	87	366	689	45	43	401	192	122	1,945.00	292	39
3		GHYON	TULU BOLO	85	427	839	46	49	516	212	139	2,313.00	347	39.60
Average of three cycle	2016	Sendafa	Adis Abeba	187	327	522	189	311	411	395	169	2,511.00	377	51
		Addis Abeba	Sendafa	169	299	514	178	307	398	377	152	2,394.00	359	52
		CHANCHO	Addis Abeba	225	575	634	418	495	583	627	828	4,385.00	658	58
		Addis Abeba	CHANCHO	323	557	639	418	450	603	638	716	4,344.00	652	55
		sebeta	TULU BOLO	85	306	626	61	68	374	173	164	1,857.00	279	42
		TULU BOLO	sebeta	91	342	713	62	77	436	220	177	2,118.00	318	43
	2017	Sendafa	Adis Abeba	108	227	349	209	261	311	251	142	1,858.00	279	52
		Addis Abeba	Sendafa	98	206	328	199	255	320	250	137	1,793.00	269	54
1		CHANCHO	Addis Abeba	420	476	688	637	542	539	517	693	4,512.00	677	51

		Addis Abeba	CHANCHO	417	506	601	604	583	595	573	740	4,619.00	693	54
		sebeta	TULU BOLO	97	354	726	73	37	402	292	208	2,189.00	328	43
		TULU BOLO	sebeta	105	370	814	73	37	417	329	216	2,361.00	354	42

APPENDEX B: Field Measured speed using radar gun

Sebeta-Tulubulo					Tulubulo-Sebeta			
S.no.	Vehicle type	Speed	Direction		S.no.	Vehicle type	Speed	Direction
1	Auto-Mobile	82	dir		1	Mini Buss	75	op
2	Large buss	75	dir		2	Large buss	40	op
3	Mini Buss	100	dir		3	Auto-Mobile	85	op
4	Mini Buss	110	dir		4	large truck	110	op
5	Mini Buss	105	dir		5	Mini Buss	55	op
6	Mini Buss	98	dir		6	large truck	57	op
7	large truck	69	dir		7	Mini Buss	51	op
8	Mini Buss	95	dir		8	Auto-Mobile	96	op
9	Bajaj	38	dir		9	large Buss	63	op
10	Auto-Mobile	95	dir		10	Auto-Mobile	125	op
11	large truck	110	dir		11	Large buss	50	op
12	Auto-Mobile	43	dir		12	large truck	57	op
13	large truck	48	dir		13	large truck	54	op
14	Mini Buss	73	dir		14	large truck	58	op
15	Auto-Mobile	45	dir		15	Mini Buss	102	op
16	large truck	59	dir		16	Mini Buss	76	op
17	Mini Buss	65	dir		17	Mini Buss	76	op
18	Auto-Mobile	62	dir		18	Mini Buss	78	op
19	small truck	86	dir		19	large truck	54	op
20	Auto-Mobile	89	dir		20	Mini Buss	111	op
21	large truck	88	dir		21	Mini Buss	85	op
22	large truck	56	dir		22	Mini Buss	90	op
23	small truck	56	dir		23	Mini Buss	120	op
24	Auto-Mobile	94	dir		24	Mini Buss	85	op
25	large truck	64	dir		25	Bajaj	38	op
26	Auto-Mobile	125	dir		26	large truck	57	op
27	Auto-Mobile	110	dir		27	large truck	40	op
28	Auto-Mobile	115	dir		28	Mini Buss	111	op
29	Auto-Mobile	120	dir		29	large truck	41	op
30	small Buss	100	dir		30	Mini Buss	86	op
31	large truck	57	dir		31	large truck	57	op
32	Auto-Mobile	80	dir		32	large truck	53	op
33	Mini Buss	95	dir		33	Mini Buss	72	op

34	Mini Buss	95	dir		34	Auto-Mobile	120	op
35	Auto-Mobile	64	dir		35	large truck	58	op
36	Mini Buss	86	dir		36	large truck	58	OP
37	Mini Buss	89	dir		37	large truck	50	OP
38	Auto-Mobile	88	dir		38	large truck	51	OP
39	large Buss	56	Dir		39	large truck	55	OP
40	large Buss	58	Dir		40	large truck	56	OP
41	Mini Buss	62	Dir		41	large truck	62	OP
42	Mini Buss	74	Dir		42	Mini Buss	109	op
43	Mini Buss	59	dir		43	Mini Buss	84	op
44	Mini Buss	95	dir		44	Auto-Mobile	115	op
45	large Buss	54	dir		45	Mini Buss	89	op
46	large truck	56	dir		46	large truck	50	op
47	Auto-Mobile	90	dir		47	large Buss	63	op
48	Mini Buss	94	dir		48	large truck	61	op
49	large truck	56	dir		49	small truck	62	op
50	large truck	59	dir		50	Mini Buss	87	op
51	Mini Buss	64	dir		51	Mini Buss	66	op
52	large Buss	61	dir		52	Mini Buss	100	op
53	Auto-Mobile	90	dir		53	mini Buss	88	op
54	large truck	54	dir		54	Auto-Mobile	75	op
55	Auto-Mobile	120	dir		55	large truck	68	op
56	large truck	64	dir		56	Mini Buss	88	op
57	small truck	55	dir		57	Large buss	53	op
58	Auto-Mobile	100	dir		58	Auto-Mobile	98	op
59	large Buss	56	dir		59	Auto-Mobile	123	op
60	Auto-Mobile	95	dir		60	Mini Buss	68	op
61	Auto-Mobile	85	dir		61	large truck	70	op
62	Large buss	78	dir		62	Mini Buss	64	op
63	Mini Buss	103	dir		63	Auto-Mobile	109	op
64	Mini Buss	113	dir		64	Mini Buss	76	op
65	Mini Buss	108	dir		65	Auto-Mobile	138	op
66	Mini Buss	101	dir		66	Large buss	63	op
67	large truck	72	dir		67	large truck	70	op
68	Mini Buss	98	dir		68	large truck	67	op
69	Truck	41	dir		69	large truck	71	op
70	Auto-Mobile	98	dir		70	Auto-Mobile	115	op
71	large truck	113	dir		71	Mini Buss	89	op
72	Auto-Mobile	46	dir		72	Mini Buss	89	op

73	large truck	51	dir		73	Mini Buss	91	op
74	Mini Buss	76	dir		74	large truck	67	op
75	Auto-Mobile	48	dir		75	Auto-Mobile	124	op
76	large truck	62	dir		76	Mini Buss	98	op
77	Mini Buss	68	dir		77	Mini Buss	103	op
78	Auto-Mobile	65	dir		78	Auto-Mobile	133	op
79	small truck	89	dir		79	Mini Buss	98	op
80	Auto-Mobile	92	dir		80	Large Truck	51	op
81	large truck	91	dir		81	large truck	70	op
82	large truck	59	dir		82	large truck	53	op
83	small truck	59	dir		83	Mini Buss	124	op
84	Auto-Mobile	97	dir		84	large truck	54	op
85	large truck	67	dir		85	Mini Buss	99	op
86	Auto-Mobile	128	dir		86	large truck	70	op
87	Auto-Mobile	113	dir		87	large truck	66	op
88	Auto-Mobile	118	dir		88	Mini Buss	85	op
89	Auto-Mobile	123	dir		89	Auto-Mobile	133	op
90	small Buss	103	dir		90	large truck	71	op
91	large truck	60	dir		91	large truck	71	OP
92	Auto-Mobile	83	dir		92	large truck	63	OP
93	Mini Buss	98	dir		93	large truck	64	OP
94	Mini Buss	98	dir		94	large truck	68	OP
95	Auto-Mobile	67	dir		95	large truck	69	OP
96	Mini Buss	89	dir		96	Mini Buss	75	OP
97	Mini Buss	92	dir		97	Mini Buss	122	op
98	Auto-Mobile	91	dir		98	Auto-Mobile	97	op
99	large Buss	59	Dir		99	Auto-Mobile	128	op
100	large Buss	61	Dir		100	Mini Buss	102	op
101	Mini Buss	65	Dir		101	small truck	63	op
102	Mini Buss	77	Dir		102	large Buss	76	op
103	Mini Buss	62	dir		103	small truck	74	op
104	Mini Buss	98	dir		104	small truck	75	op
105	large Buss	57	dir		105	Mini Buss	100	op
106	large truck	59	dir		106	Mini Buss	79	op
107	Auto-Mobile	93	dir		107	Mini Buss	113	op
108	Mini Buss	97	dir		108	mini Buss	101	op
109	large truck	59	dir		109	Auto-Mobile	88	op
110	large truck	62	dir		110	Mini Buss	81	op
111	Mini Buss	67	dir		111	Mini Buss	79	op

112	large Buss	64	dir		112	Mini Buss	113	op
113	Auto-Mobile	93	dir		113	Auto-Mobile	101	op
114	large truck	57	dir		114	Auto-Mobile	88	op
115	Auto-Mobile	123	dir		115	Mini Buss	81	op
Total Sum(km/hr)		9197			Total Sum(km/hr)		9247.0	
Average(km/hr)		80.0			Average(km/hr)		80.4	

APPENDIX-C: Sample Software Output for Current and Future Year

Sample software output Addis Ababa-Sendafa for current condition

```
________________________Percent Time-Spent-Following_______________________

Direction                                    Analysis(d)        Opposing (o)
PCE for trucks, ET                               1.1                 1.1
PCE for RVs, ER                                  1.0                 1.0
Heavy-vehicle adjustment factor, fHV             0.951               0.951
Grade adjustment factor,(note-1) fg              1.00                1.00
Directional flow rate,(note-2) vi                322    pc/h         334     pc/h
Base percent time-spent-following,(note-4) BPTSFd  35.0   %
Adjustment for no-passing zones, fnp               15.7
Percent time-spent-following, PTSFd                42.7   %

_______________Level of Service and Other Performance Measures______________

Level of service, LOS                              D
Volume to capacity ratio, v/c                      0.21
Peak 15-min vehicle-miles of travel, VMT15         237     veh-mi
Peak-hour vehicle-miles of travel, VMT60           834     veh-mi
Peak 15-min total travel time, TT15                5.4     veh-h
Capacity from ATS, CdATS                           1408    veh/h
Capacity from PTSF, CdPTSF                         1616    veh/h
Directional Capacity                               1408    veh/h

____________________________Passing Lane Analysis___________________________

Total length of analysis segment, Lt                         3.1     mi
Length of two-lane highway upstream of the passing lane, Lu  0.5     mi
Length of passing lane including tapers, Lpl                         mi
Average travel speed, ATSd (from above)                      44.3    mi/h
Percent time-spent-following, PTSFd (from above)             42.7
Level of service, LOSd (from above)                          D

___________________Average Travel Speed  with Passing Lane__________________

Downstream length of two-lane highway within effective
    length of passing lane for average travel speed, Lde     1.70    mi
Length of two-lane highway downstream of effective
    length of the passing lane for average travel speed, Ld  0.90    mi
Adj. factor for the effect of passing lane
    on average speed, fpl                                    1.10
Average travel speed including passing lane, ATSpl           45.5
Percent free flow speed including passing lane, PFFSpl       89.1    %
```

Percent Time-Spent-Following

Direction	Analysis(d)		Opposing (o)	
PCE for trucks, ET	1.1		1.1	
PCE for RVs, ER	1.0		1.0	
Heavy-vehicle adjustment factor, fHV	0.951		0.951	
Grade adjustment factor,(note-1) fg	1.00		1.00	
Directional flow rate,(note-2) vi	322	pc/h	334	pc/h
Base percent time-spent-following,(note-4) BPTSFd	35.0	%		
Adjustment for no-passing zones, fnp	15.7			
Percent time-spent-following, PTSFd	42.7	%		

Level of Service and Other Performance Measures

Level of service, LOS	D	
Volume to capacity ratio, v/c	0.21	
Peak 15-min vehicle-miles of travel, VMT15	237	veh-mi
Peak-hour vehicle-miles of travel, VMT60	834	veh-mi
Peak 15-min total travel time, TT15	5.4	veh-h
Capacity from ATS, CdATS	1408	veh/h
Capacity from PTSF, CdPTSF	1616	veh/h
Directional Capacity	1408	veh/h

Passing Lane Analysis

Total length of analysis segment, Lt	3.1	mi
Length of two-lane highway upstream of the passing lane, Lu	0.5	mi
Length of passing lane including tapers, Lpl		mi
Average travel speed, ATSd (from above)	44.3	mi/h
Percent time-spent-following, PTSFd (from above)	42.7	
Level of service, LOSd (from above)	D	

Average Travel Speed with Passing Lane

Downstream length of two-lane highway within effective length of passing lane for average travel speed, Lde	1.70	mi
Length of two-lane highway downstream of effective length of the passing lane for average travel speed, Ld	0.90	mi
Adj. factor for the effect of passing lane on average speed, fpl	1.10	
Average travel speed including passing lane, ATSpl	45.5	
Percent free flow speed including passing lane, PFFSpl	89.1	%

```
______________Percent Time-Spent-Following with Passing Lane______________

Downstream length of two-lane highway within effective length
   of passing lane for percent time-spent-following, Lde    10.83   mi
Length of two-lane highway downstream of effective length of
   the passing lane for percent time-spent-following, Ld    -8.23   mi
Adj. factor for the effect of passing lane
   on percent time-spent-following, fpl                     0.60
Percent time-spent-following
   including passing lane, PTSFpl                           30.1    %

_____Level of Service and Other Performance Measures with Passing Lane _____

Level of service including passing lane, LOSpl     C
Peak 15-min total travel time, TT15                5.2     veh-h
```

Sample Software Analysis Result for Projected Year

Software Analysis Result; Addis Ababa - Sendafa

2018

HCS 2010: Two-Lane Highways Release 6.70

Phone: Fax:
E-Mail:

Directional Two-Lane Highway Segment Analysis

Analyst	Chirotaw Yirga
Agency/Co.	
Date Performed	15/10/2017
Analysis Time Period	For One year
Highway	Adids Ababa-Debrebrihan road c
From/To	5km segment b/n Addis-Sendafa
Jurisdiction	AASTU
Analysis Year	2018
Description	for projected traffic

Input Data

Highway class	Class 1		Peak hour factor, PHF	0.88	
Shoulder width	4.9	ft	% Trucks and buses	51	%
Lane width	11.5	ft	% Trucks crawling	0.0	%
Segment length	3.1	mi	Truck crawl speed	0.0	mi/hr
Terrain type	Level		% Recreational vehicles	0	%
Grade: Length	-	mi	% No-passing zones	0	%
Up/down	-	%	Access point density	0	/mi

Analysis direction volume, Vd 285 veh/h
Opposing direction volume, Vo 295 veh/h

______________________________Average Travel Speed__________________

Direction	Analysis(d)		Opposing (o)	
PCE for trucks, ET	1.3*		1.3*	
PCE for RVs, ER	1.0		1.0	
Heavy-vehicle adj. factor,(note-5) fHV	0.865		0.865	
Grade adj. factor,(note-1) fg	1.00		1.00	
Directional flow rate,(note-2) vi	353	pc/h	367	pc/h

Free-Flow Speed from Field Measurement:

Field measured speed,(note-3) S FM	50	mi/h
Observed total demand,(note-3) V	115	veh/h

Estimated Free-Flow Speed:

Base free-flow speed,(note-3) BFFS	-	mi/h
Adj. for lane and shoulder width,(note-3) fLS	-	mi/h
Adj. for access point density,(note-3) fA	-	mi/h
Free-flow speed, FFSd	51.0	mi/h
Adjustment for no-passing zones, fnp	1.2	mi/h
Average travel speed, ATSd	44.3	mi/h
Percent Free Flow Speed, PFFS	86.8	%

__________________________Percent Time-Spent-Following______________

Direction	Analysis(d)		Opposing (o)	
PCE for trucks, ET	1.1		1.1	
PCE for RVs, ER	1.0		1.0	
Heavy-vehicle adjustment factor, fHV	0.951		0.951	
Grade adjustment factor,(note-1) fg	1.00		1.00	
Directional flow rate,(note-2) vi	322	pc/h	334	pc/h
Base percent time-spent-following,(note-4) BPTSFd	35.0	%		
Adjustment for no-passing zones, fnp	15.7			
Percent time-spent-following, PTSFd	42.7	%		

_________________Level of Service and Other Performance Measures________

Level of service, LOS	D	
Volume to capacity ratio, v/c	0.21	
Peak 15-min vehicle-miles of travel, VMT15	237	veh-mi
Peak-hour vehicle-miles of travel, VMT60	834	veh-mi
Peak 15-min total travel time, TT15	5.4	veh-h
Capacity from ATS, CdATS	1408	veh/h

_____________________Average Travel Speed with Passing Lane_____________________

Downstream length of two-lane highway within effective
length of passing lane for average travel speed, Lde 1.70 mi
Length of two-lane highway downstream of effective
length of the passing lane for average travel speed, Ld 0.10 mi
Adj. factor for the effect of passing lane
on average speed, fpl 1.10
Average travel speed including passing lane, ATSpl 46.6
Percent free flow speed including passing lane, PFFSpl 91.3 %

_________________Percent Time-Spent-Following with Passing Lane_________________

Downstream length of two-lane highway within effective length
of passing lane for percent time-spent-following, Lde 10.83 mi
Length of two-lane highway downstream of effective length of
the passing lane for percent time-spent-following, Ld -9.03 mi
Adj. factor for the effect of passing lane
on percent time-spent-following, fpl 0.60
Percent time-spent-following
including passing lane, PTSFpl 29.2 %

______Level of Service and Other Performance Measures with Passing Lane ______

Level of service including passing lane, LOSpl C
Peak 15-min total travel time, TT15 5.1 veh-h